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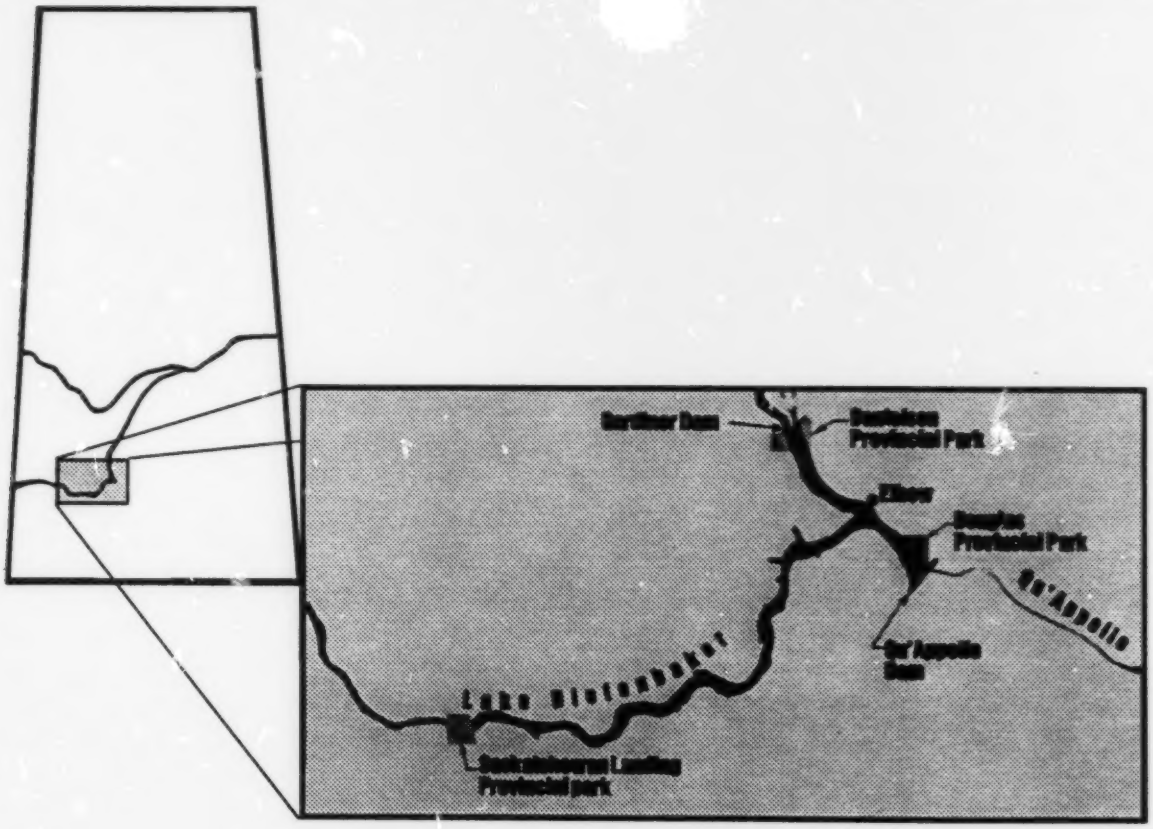
An Appraisal of the Lake Diefenbaker Commercial Whitefish Fishery, 1976-85

Fisheries Technical Report 92-4



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AN APPRAISAL OF THE LAKE DIEFENBAKER COMMERCIAL WHITEFISH FISHERY, 1976-85.

by

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FISHERIES TECHNICAL REPORT 92 - 4

Saskatchewan Natural Resources

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EXECUTIVE SUMMARY

SITUATION

Lake Diefenbaker had supported a whitefish commercial fishery from 1976 until 1985 when all indications pointed to severe depletion of larger fish most vulnerable to commercial fishing. Earlier studies had suggested that the Lake Diefenbaker whitefish were fast-growing fish with a rather short life span of 6-7 years and that there was little chance of successful natural reproduction because of severe winter water draw-down. It was then recommended the catchable stock should be harvested as quickly as possible.

The objectives of the present study are to appraise the fishery and address the following issues relative to the whitefish population : 1) current population status, 2) extent to which the population perpetuates itself through natural reproduction, 3) movement and distribution, 4) level of sustainable harvest, and 5) resumption of commercial fishing.

RESULTS

The Lake Diefenbaker whitefish population has proliferated remarkably since the impoundment in 1967, because of 1) enhancement of the indigenous river population in an expanded environment, 2) stocking of 7.7 million fry, and 3) successful natural reproduction in a much extended spawning habitat.

Growth of the Lake Diefenbaker whitefish is very fast in the first three years of life and then slows down considerably. As a result, the annual marks on the scales of fish older than three years old become indiscernible. Information on fish age, based on otolith and fin rays, suggests that the population is comprised of fish as old as 17 years of age, comparable to other populations in Saskatchewan.

As evidenced from the test-netting results of 1967-91, the current population is continually expanding and its density ranks very high among Saskatchewan lakes. It appears that the fish spawn successfully in areas beyond the effect of winter water draw-downs.

During the early years after impoundment of the South Saskatchewan River, the whitefish population was restricted mainly to the north end between Gardiner Dam and Qu'Appelle Arm. However, it is now widely scattered throughout the entire lake. The fish are mostly concentrated in water deeper than 20 m in the summer months, move toward shallow water in September-October and during the spawning season in mid-November. There is also a wide range of post-spawning migration throughout the lake. Many fish migrate as much as 140 km in one season.

The annual commercial catch has fluctuated from 3,963 kg to 112,741 kg in 10 years, averaging 71,164 kg. The fishing effort (100 m net/day) has also varied greatly from 124 to 1,280 units, averaging 623. Inclement weather conditions in the fall have often hampered fishing operations and disrupted concentration of fish.

With 14.0 cm (5.5") being the legal mesh net, the fishery has harvested predominantly fish in the 43-47 cm range, weighing 1.3-1.8 kg. These fish are 8 - 13 years in age. The average size of fish in the catch has persistently decreased from 1979 to 1985 due to the gradual depletion of fish over 45 cm, but the change has been slight because of the effect of gill net selectivity.

The south end (Saskatchewan Landing - Beaver Flat) fishery has been more productive than its north end (Riverhurst - Qu'Appelle Arm - Gardiner Dam) counterpart, because 1) the fish caught in the north end are slightly smaller, 2) there is a heavier concentration of fish in the south end during the fall season, and 3) the north end fishery is more vulnerable to inclement weather.

The commercial fishery has caught predominantly mature fish, with a sex ratio of 56% vs 44% in favour of females. Among the females, approximately 46% are spawning fish, 53% non-spawning mature fish, and only 1% immature fish. All males are mature and predominantly spawning. There are also senile fish of both sexes in the catch.

Based on the results of a tagging study in 1982-84, the following parameters of the catchable fish (31-55 cm) in the lake are derived:

1. The catchable stocks were estimated at 620,371 and 534,702 fish in 1983 and 1984 respectively;

2. The annual survival rate was 41%, or total mortality rate 59%, during the study period;

3. The rate of fishing (F) was 11.8% in 1983 and 3.2% in 1984. This is low because of the dwindling number of fish over 45 cm and the significant increase of fish under 40 cm. The 14.0 cm mesh net is not effective toward the latter group; and

4. Catchability coefficients were estimated at 0.000144 in 1983 and 0.000135 in 1984, a slight decrease in fishing efficiency in light of decreased stock vulnerable to the 14.0 cm mesh net.

Analysis of the virtual population (actually utilized stock) has resulted in the following parameters, which are mainly relevant to fish over 43 cm in length:

a. maximum stock size = 179,272 fish;

b. rate of fishing at sustainable level = 0.74;

c. stock size at sustainable level = 89,100 fish; and

d. maximum sustainable yield = 66,400 fish

These parameters indicate a moderate population of large fish are available to the fishery, and that overfishing in four consecutive years, 1980-83, with a mean harvest of 79,100 fish, caused the fishery to collapse, because fish most susceptible to the 14.0 cm mesh gill nets are no longer present in sufficient numbers to support the fishery.

There is, however, other evidence indicating depletion of the most vulnerable sector of the population. This is reflected in the steady declines of catch per unit of effort since 1982 in commercial fishing and the proportion of the largest fish in both the commercial and test net samples. The unusually low commercial productions in 1984 and 1985 exemplified serious depletion of once plentiful fish of 45 cm or larger.

Since the cessation of commercial fishing in 1986, the stock size of those fish most vulnerable to the 14 cm mesh net has not recovered significantly. The pace of recovery remains slow, due to the slow growth rate of fish older than 3 years, and perhaps more importantly, due to a new ecological balance in which the newly proliferated lake dwelling species, such as ciscoes, walleye, perch and suckers, have filled in the food web niche left behind from the depleted portion of the whitefish population. However, there remains a hugh population of whitefish in Lake Diefenbaker, mostly of fish under 40 cm.

Since the impoundment, the fish community in lake Diefenbaker has undergone two major changes: an enormous increase in the biomass of fish; and the replacement of riverine species (goldeye, mooneye) by lacustrine (lake) species (whitefish, walleye, ciscoes, etc.) as the dominant group.

Resumption of commercial fishing is justified, in view of a huge stock of catchable fish the lake. The fishery, however, must be managed under different regulations due to changes in their size composition. Recommendations regarding a new fishery are as follows:

1. The whitefish commercial fishery be reinstated in Lake Diefenbaker using 10.2 cm or 11.4 cm stretched mesh, with an initial total allowable catch (TAC) of 50,000 kg;

2. The new fishery be monitored annually to ensure that the age at full recruitment remains above 6 years, that the survival rate is greater than 0.5, and that at least 80% of the fish in the fishery are sexually mature;

3. The game fish tolerance be 2,500 kg for walleye and 2,500 kg for pike; and

4. The fishing season remains in the fall from September 15 to November 15;

ACKNOWLEDGEMENTS

The author wish to acknowledge the assistance in field data collection from numerous Fisheries and Regional staff: Keith Dahl, Ron Jensen, Gordon Sedgewick, Rick Orr, Michelle Mathias, G. Banks, and W. W. Whiting. Cooperation from the commercial fishermen in obtaining fish measurements and information on fishing effort is gratefully appreciated.

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1. INTRODUCTION

Lake Diefenbaker (Fig. 1), an impounded reservoir of the South Saskatchewan River, came into being in 1967. At full supply level (FSL), 556.87 m, the lake is 225 km long, covers 430 sq. km surface area, and has a water volume of 9.4 billion cubic meters. The mean and maximum depths of the lake are 21.9 m and 60 m respectively (Royer 1972a). The main uses of Lake Diefenbaker are power generation, irrigation, flood control, domestic and industrial water supply, and recreation.

At least 25 species of fish are known to exist in the lake. These include lake whitefish, walleye, sauger, yellow perch, northern pike, cisco, burbot, goldeye, mooneye, sturgeon, lake trout, and a variety of suckers and minnow species (Royer 1972a). Based on Royer's recommendation, an extensive fish stocking program was implemented from 1969 to 1975:

Whitefish	1969	4,000,000	fry
	1972	3,750,000	"
	(Total)	(7,750,000)	
Lake trout	1970	572,000	fingerlings
	1971	350,000	"
	1972	250,000	"
	(Total)	(1,172,000)	
Walleye	1969	3,500,000	fry
	1970	3,000,000	"
	1971	3,250,000	"
	1975	3,000,000	"
	(Total)	(12,750,000)	

The whitefish stocking was intended for creating a forage base for lake trout and the possible development of a viable commercial fishery. Lake trout and walleye were stocked to enhance the existing meagre populations and improve angling quality. Subsequent studies (Royer 1972b, Smith 1974 and Hunt 1976) all indicated that larger populations of whitefish and walleye were developing in the lake, while lake trout failed to proliferate as anticipated.

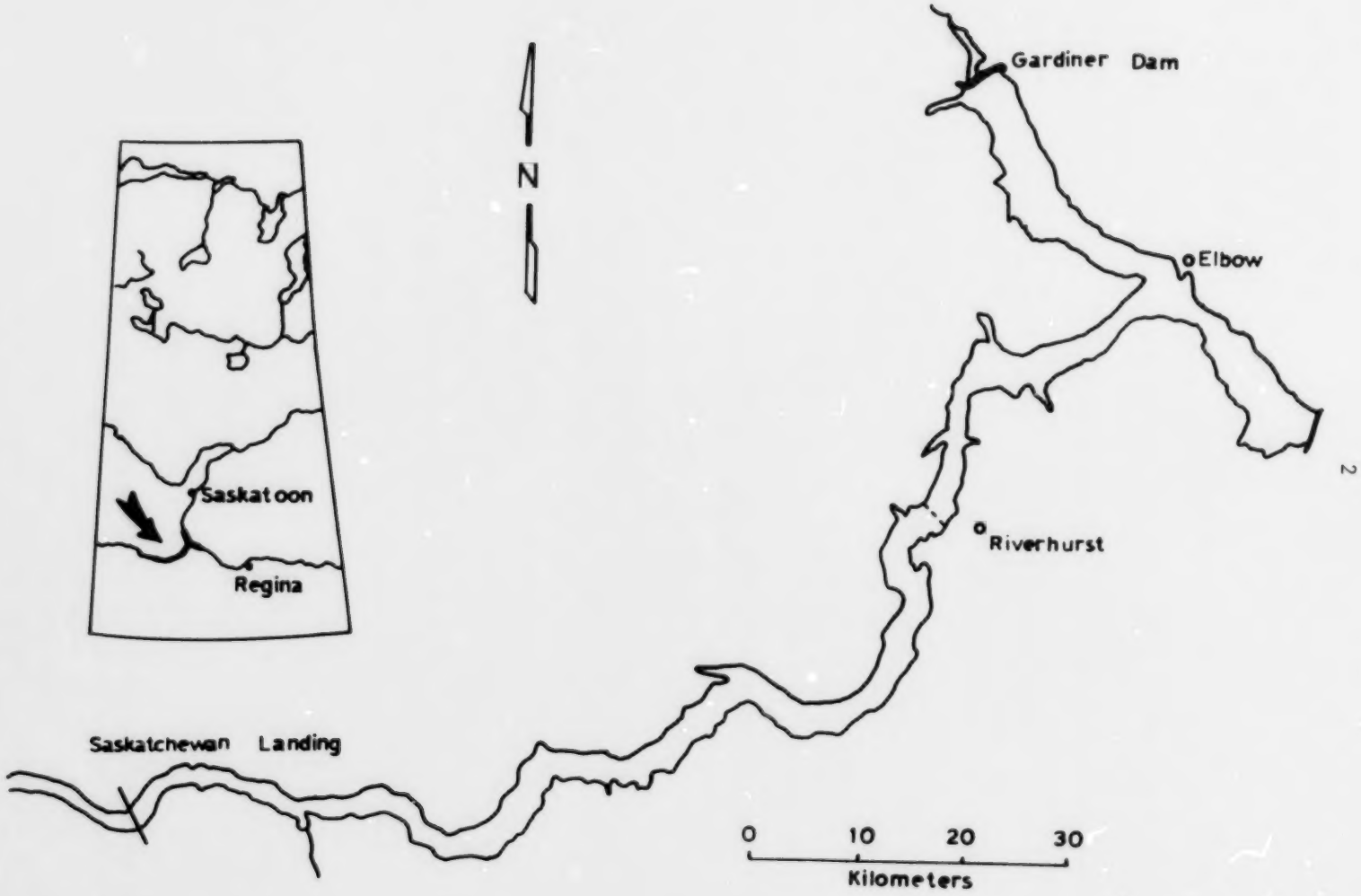


Fig. 1. Lake Diefenbaker.

Based on fish ages determined by examining fish scales, earlier studies on the Lake Diefenbaker whitefish population have all stated the growth rate of the fish as "phenomenal", especially during the first three years of life. Furthermore, these fish rarely reached ages older than six years, a rather short life span compared to other Saskatchewan whitefish populations. Management decisions for the fish population then were to harvest the usable stock as soon as possible before they died of old age.

Following a successful pilot commercial fishery in two previous years, the Lake Diefenbaker commercial fishery was officially established in 1978. The fishery was regulated by an annual quota of 90,703 kg (200,000 lb), a legal mesh net of 14 cm (5.5 in), a fall fishing season and split quotas between two geographic zones, north end and south end (Saskatchewan Landing). For a detailed chronical development of the fishery, refer to Hunt (1976), Swanson (1977) and Wallin (1978). Regulations and guidelines respecting the fishery are given in Appendix 1.

For seven consecutive years, from 1977-83, the annual harvest from the fishery averaged 93,413 kg, slightly above the lake limit. However, in the two subsequent years, 1984 and 1985, the fishery was seriously hampered by inclement weather and drastic decline in catch. Harvests in 1984 and 1985 were only 10,292 kg and 3,963 kg respectively. Since 1986 the lake has been closed to commercial fishing. A series of test nettings were conducted in 1985-91 to assess the whitefish population, in light of a possible population collapse.

The main objectives of the present study are to appraise the commercial fishery and address the following issues concerning the whitefish population: 1) current population status; 2) extent of natural recruitment; 3) movement and distribution; 4) allowable level of harvest; and 5) resumption of commercial fishing.

2. METHODS

2.1 TESTNETTING

Since 1967, there have been 16 years of testnetting on the lake to evaluate the fish community structure. Table 1 summarizes the netting results only in terms of whitefish catch.

2.2 SAMPLING OF THE COMMERCIAL FISHERY

Length and weight of fish from random samples of commercial catches were collected in each of the ten years, 1976-85. In addition, information on sex, maturity and spawning conditions of fish was recorded in three seasons, 1982-84. In early years of

Table 1. Summary of test net results of whitefish from Lake Diefenbaker, 1967-91.

Year	Gear*	Length of net (m)	No. of fish caught	No. of fish per 100 m	Time of testnetting
1967	SG	6,172	6	0.09	June-August
1968	SG	3,703	6	0.15	June-August
1969	SG	4,389	21	0.48	June-August
1972	SG	2,588	87	3.36	June-July
1973	SG	2,103	95	4.52	June-Nov.
1974	SG	1,783	113	6.34	May-Sept.
1975	LMN	3,840	595	15.50	June-Nov.
1977	SG	2,469	244	9.88	May
1980	SG	1,920	361	18.80	May
1983	SG	4,663	769	16.49	June-August
1985	SG	69	40	5.80	October
	LMN_1	503	395	78.53	Oct.-Nov.
1986	LMN_2	695	116	16.70	May
1987	SG	1,310	469	39.10	July-August
1988	SG	1,050	354	36.90	July-August
1989	SG	525	174	36.30	August
1991	SG	1,180	425	39.40	August

* SG : standard gang gillnet set consisting of six nets of 3.8 cm, 5.1 cm, 7.6 cm, 10.2 cm, 12.7 cm and 14 cm meshes.

LMN_1 : large mesh nets of 10.2 cm, 11.4 cm, 12.7 cm and 14.0 cm.
LMN_2 : large mesh nets of 11.4 cm, 12.7 cm and 14 cm.

fishing, only fish scales were collected for ageing. Otoliths and fin rays were collected in latter years for ageing validation. The annual harvest data in each of the 10 fishing seasons, and information on fishing effort from 1976 to 1981, were provided by conservation officers in the Saskatoon and Swift Current Regions. Fishing efforts from 1982 to 1985 were obtained through direct interviews with fishermen.

2.3 FISH TAGGING

Fish were tagged in conjunction with the whitefish spawning operation in 1982 and 1983. In both years, 5.1 - and 7.6 cm mesh nets were used to capture the fish.

A total of 1,220 tagged fish were released, including 701 fish from the vicinity near Saskatchewan Landing Provincial Park and 519 fish from Coteau Bay and Danielson Provincial Park. Each fish was tagged with a numbered monel strap tag (size #4) to the caudal peduncle by means of pliers (Fig. 2). All tagged fish were kept in a holding pen overnight and only live ones in good condition were released the next day.

2.4 TAG RECOVERY

Reporting the capture of tagged fish was entirely on a volunteer basis. To encourage commercial fishermen and anglers to return both fish and tags, a reward system was implemented in 1984, offering $10 per return of both fish and tag and $2 for tag return only. A total of nine recaptures were reported during the 1984 commercial fishing season, including four fish.

2.5 FISH AGEING

In the early years of the Lake Diefenbaker whitefish studies only fish scales were used for age determination. In 1981 three media (scales, fin rays and otoliths) from 50 whitefish were selected for ageing. Figure 3 shows the three ageing results. Five age classes (2-6 yr) were observed with the scale method, 6 age classes (4-8 and 13 yr) with fin rays and 10 age classes (3-13) with otoliths. It appears the scale method under-estimates the ages of old fish.

The four tagged fish recaptured in 1984 included one fish released in 1982 and three others released in 1983. The scale ages of these four fish at the time of the tagging study were 3, 5 (two fish) and 6 years, but remained unchanged in 1984. This substantiates the discrepancies in Figure 3 and in effect, invalidates the scale ageing results, as fish older than three years are generally under-aged by this method.

Fig. 2. Caudal peduncle of whitefish showing the attachment of a monel strap tag.

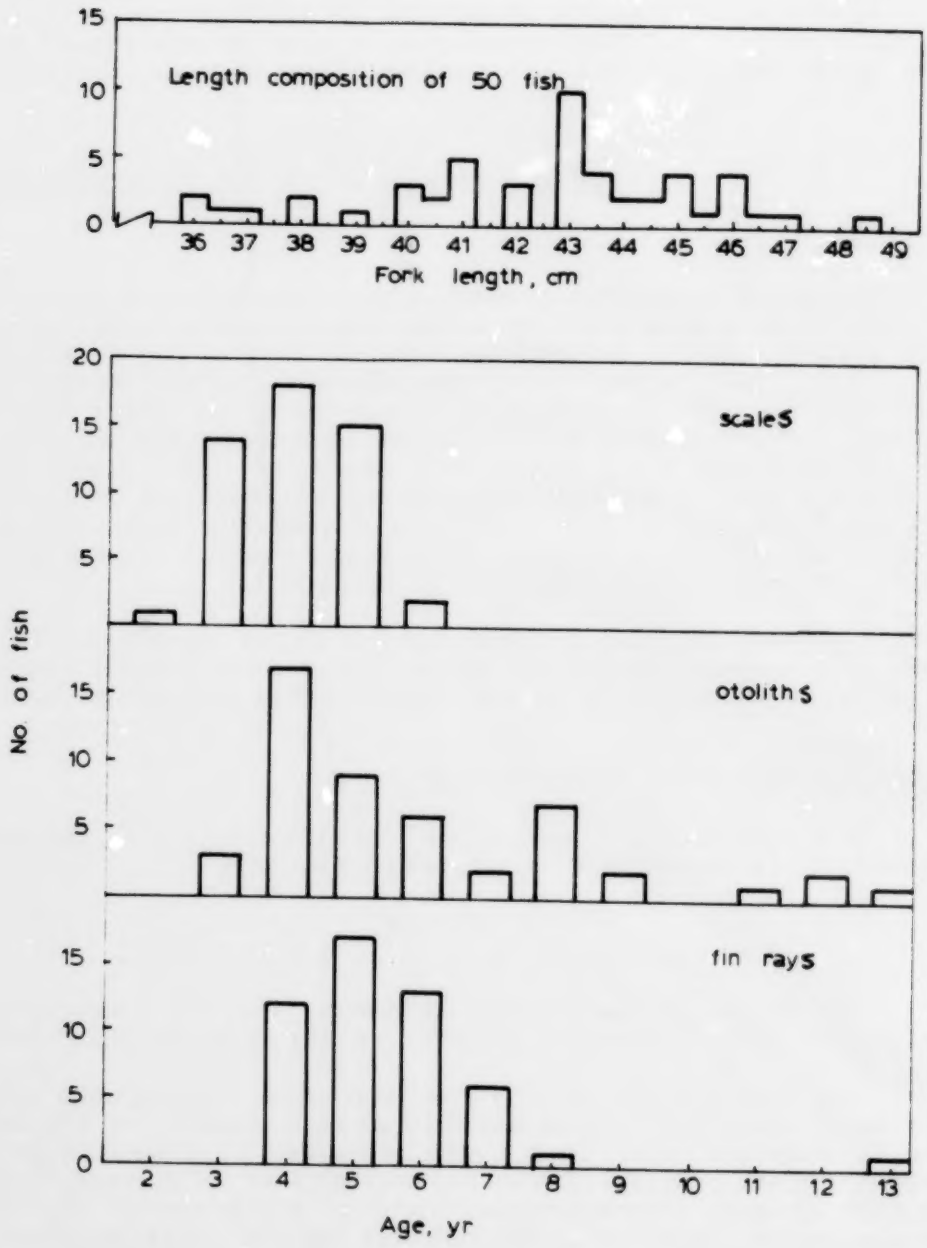


Fig.3. Comparison of three ageing methods ; scale, otolith and fin ray, from 50 Lake Diefenbaker whitefish collected in the 1981 commercial fishery.

In 1985, otoliths from 564 whitefish collected from test netting and commercial sampling were used for age determination. The ages of whitefish from other years were then extrapolated from the 1985 ageing results using the stratification method described by Ketchen (1950). Age compositions used in the cohort analysis of the commercial catches are derived from the same extrapolation.

3. AGE AND GROWTH OF LAKE DIEFENBAKER WHITEFISH

3.1 AGE

Figure 4 shows the growth of Lake Diefenbaker whitefish, based on the 1985 sample aged by examining otoliths. It indicates that the growth rate is exceptionally fast during the first three years of life, then slows down considerably after that. The fish continue to grow at much slower rate until at about 11 or 12 years of age. Beyond this point, there is hardly any sign of growth. It is possible that after 3-4 years of life, Lake Diefenbaker whitefish may or may not lay discernible circuli on scales because of the retarded growth rate and hence the annual rings may be either not shown or so closely packed together that distinction of yearly growth becomes extremely difficult.

Contrary to the earlier notion based on the scale ages, the Lake Diefenbaker whitefish have rather slow growth rates and long life spans compared to other Saskatchewan whitefish populations.

3.2 LENGTH-WEIGHT RELATIONSHIP

The length (L) - weight (W) relationship of Lake Diefenbaker whitefish is expressed as follows (Fig. 5):

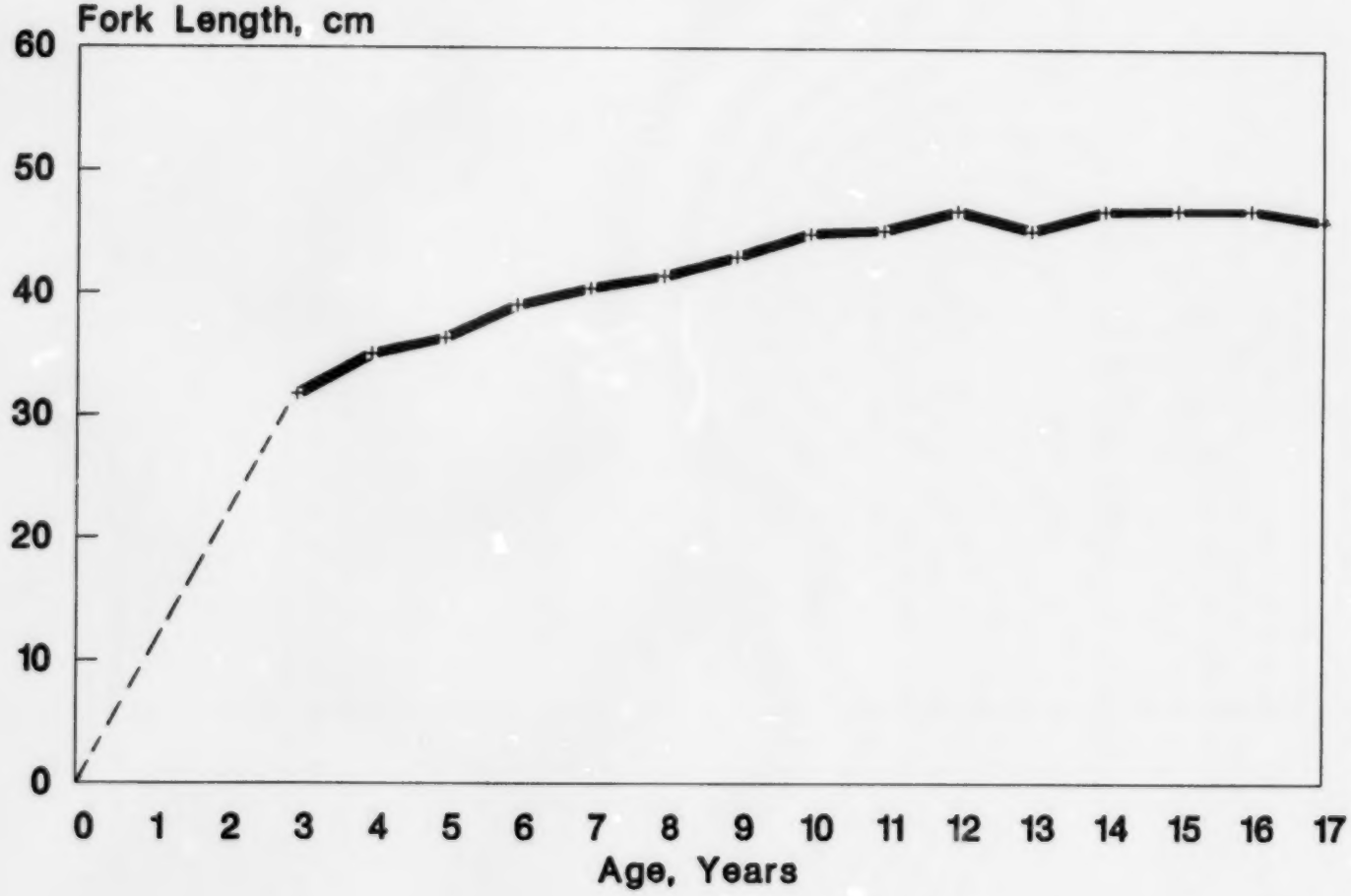
$$W = 1.158 \times 10^{-5} L^{3.0423} \qquad (r = 0.9963)$$

The value of the length exponent, 3.0423, indicates that the weight of fish increases roughly at the cube of body length.

The assumption of fast growth rate during the first three years, followed by a considerably slower growth for the population, can be substantiated to a certain degree by comparing the length-weight relationships of two size-groups of fish, under and over 40 cm fork length. The average length of a three-year old fish, based on scale age, is 40 cm. The calculated L-W relationships for these two groups of fish are :

$$\text{under 40 cm:} \quad W = 6.9801 \times 10^{-6} L^{3.2011} \qquad (r = 0.9938)$$

Fig. 4. Growth of Lake Diefenbaker Whitefish, based on the 1985 sample.



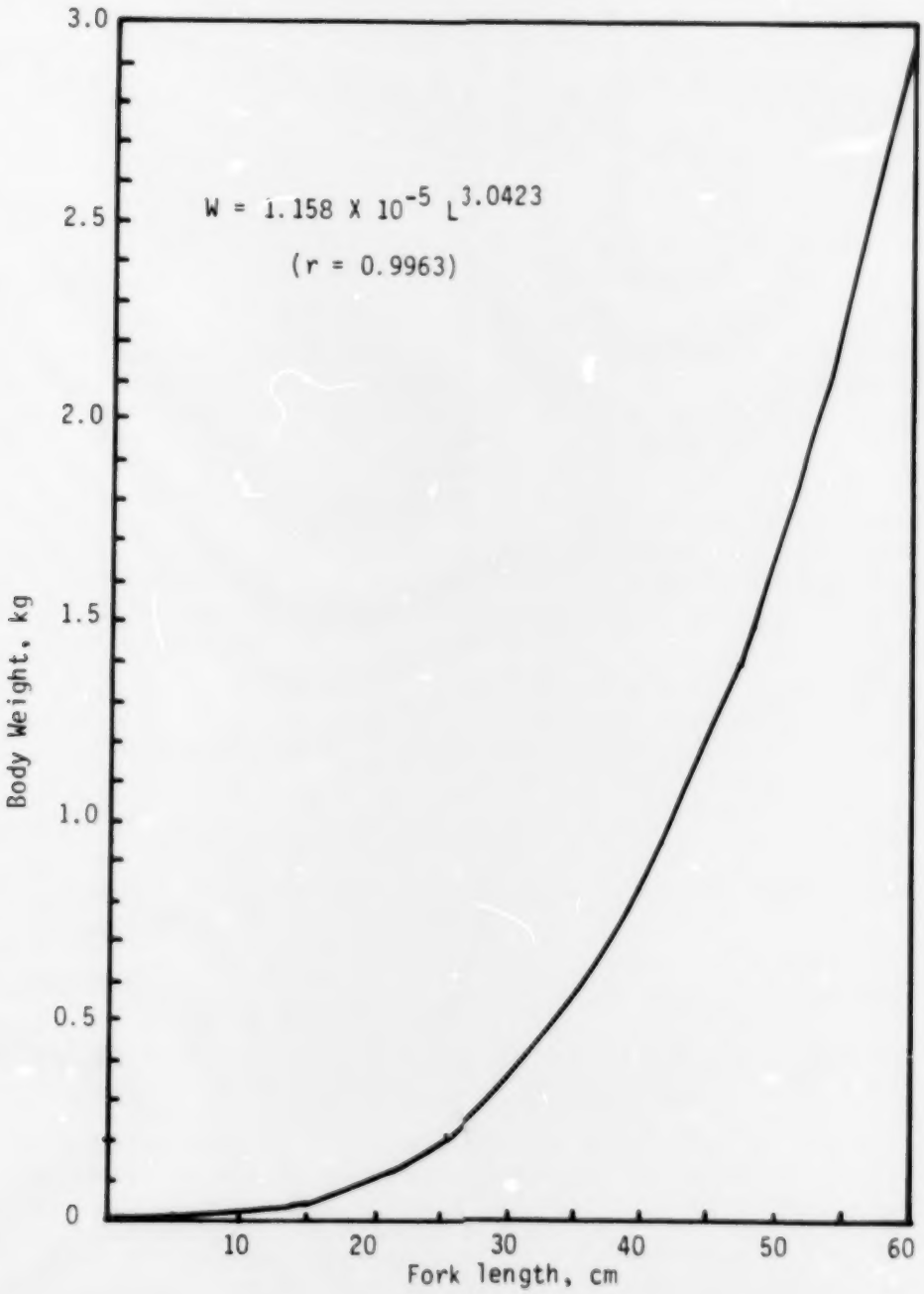


Fig. 5. Length(L)-weight(W) relationship of Lake Diefenbaker whitefish, based on the 1983 standard gang catch.

over 40 cm: $W = 5.3911 \times 10^{-5} L^{2.6444}$ ($r = 0.8751$)

The body weight of fish less than 40 cm increases at a rate significantly greater than the cube of body weight, whereas that of larger fish increases well below the cube of length, indicating a retarded growth rate for these fish.

4. STATUS OF THE WHITEFISH POPULATION

4.1 POPULATION STRUCTURE

Whitefish existed in the Saskatchewan River before 1967. Adult fish were commonly taken in survey nets in 1967-69 (Royer 1972a). The impounded reservoir has created ample whitefish habitat with summer water temperature less than 15 C and dissolved oxygen more than 4 ppm (Fig. 6). Being cold water fish, the population had adapted well in the new environment as expected, and steadily expanded in magnitude. This is evidenced in Fig. 7 and 8 which show the numbers of fish caught per 100 m of net and length distributions of all gill net catches from 1967 to 1980. The stocking of 7.5 million fry in 1969 and 1972 undoubtedly also contributed to the population expansion. This is clearly obvious in the 1973 catch of 20-23 cm fish, relative to the 1972 stocking.

The size composition of the whitefish population has also changed noticeably over the years in that fish over 40 cm long are now comprising a significantly greater proportion than during the few years after impoundment (Fig. 7 and 8). In the riverine environment, the survival and proliferation of the fish were limited by the lack of deep and cold habitat. Improved survival and population proliferation of the indigenous and stocked whitefish have become evident as early as in 1972 and 1973, and continued during the early stage of commercial fishing. Based on comparative data of gill net catches, the current Lake Diefenbaker whitefish population ranks the highest in magnitude among the 12 selective lakes in southern and central Saskatchewan (Table 2).

Figure 9 illustrates what has become the whitefish population in Lake Diefenbaker after 10 years of commercial fishing. The mode of the standard gang gill net catch curve has shifted from 45 cm in 1977 and 1980 to 39-41 cm in 1983, and to 36 cm in 1991. It clearly indicates that fish over 45 cm, which had been the mainstay of the commercial fishery, have been depleted significantly and replaced by smaller fish in larger quantity.

4.2 NATURAL REPRODUCTION - RECRUITMENT

The pattern of population expansion, as shown in Fig. 7-9, indicates strong recruitment through natural reproduction. In

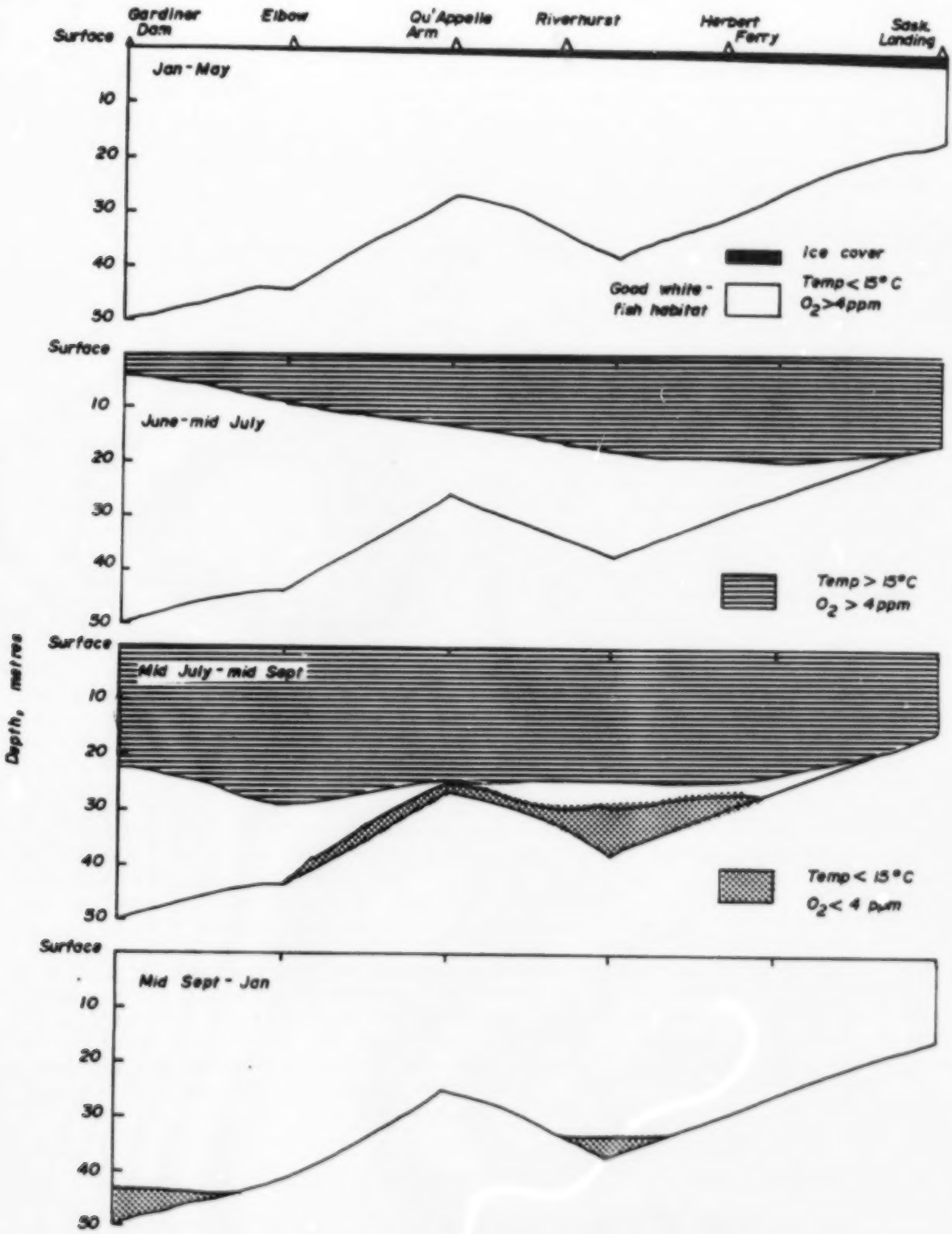


Fig. 6. Whitefish habitat, as indicated by suitable temperature and dissolved oxygen levels in Lake Diefenbaker.

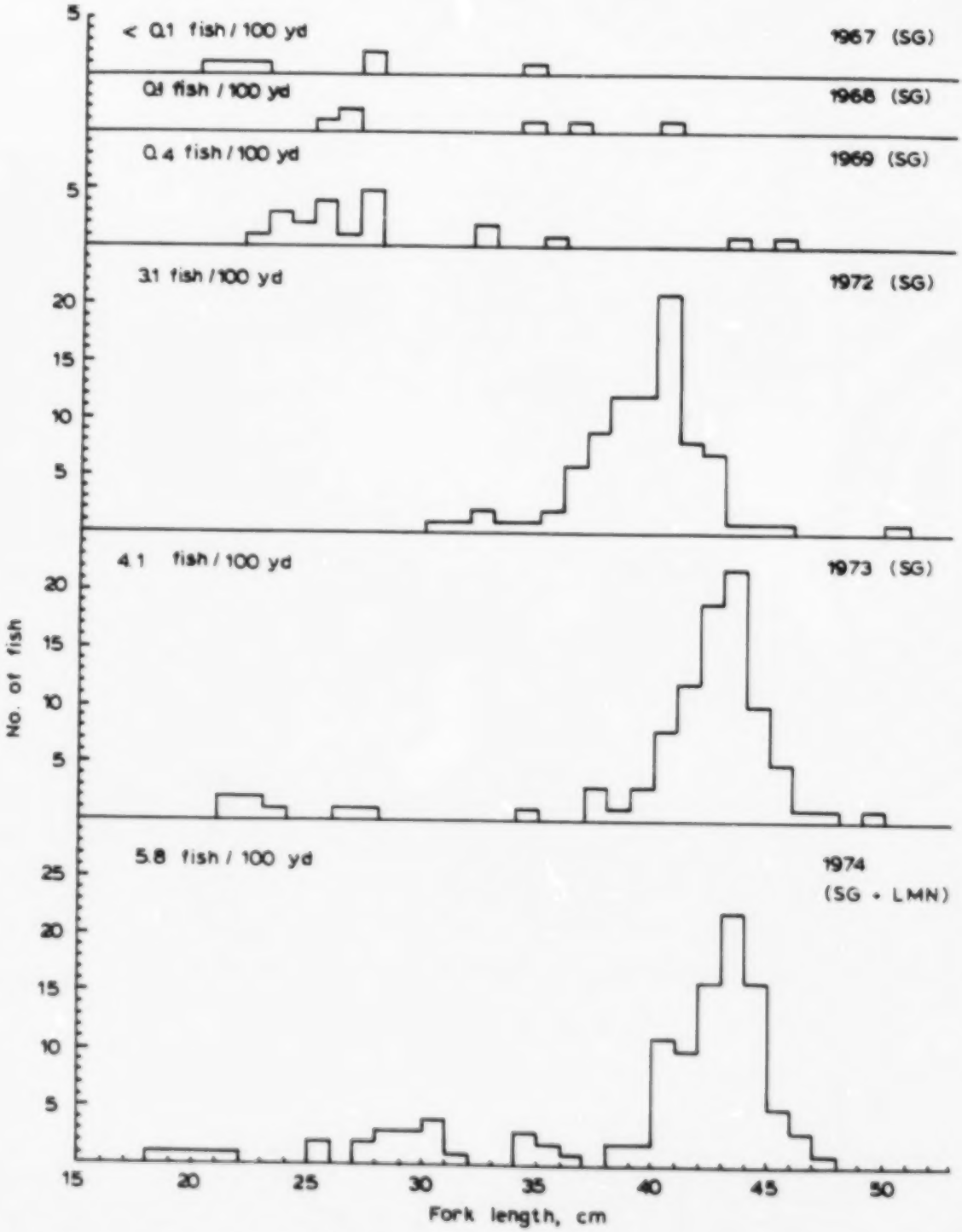


Fig. 7. Length-frequency distribution of whitefish caught with standard gangs (SG) and large mesh nets (LMN) in Diefenbaker Lake 1967-74.

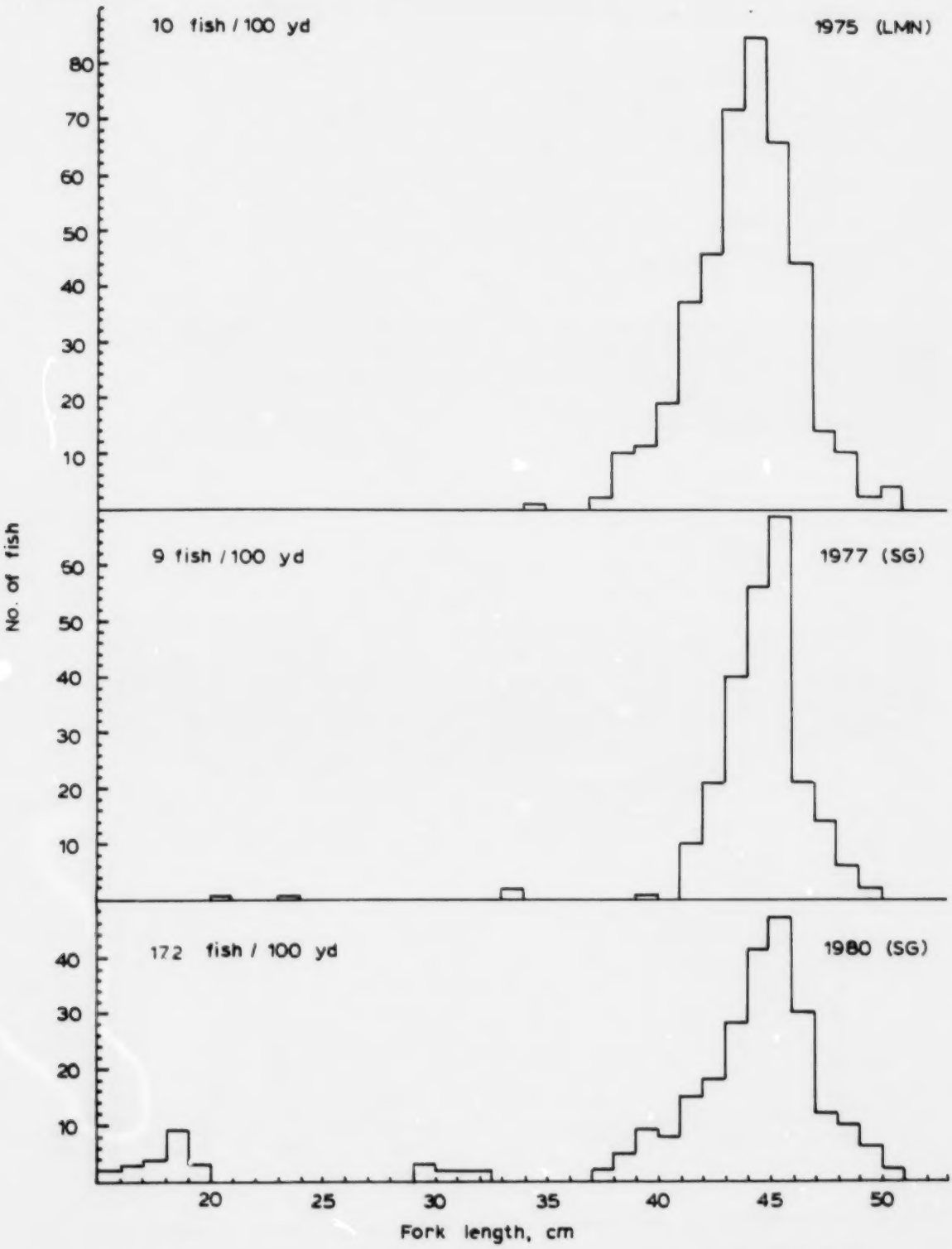


Fig. 8. Length-frequency distribution of whitefish caught with standard gangs (SG) and large mesh nets (LMN) in Diefenbaker Lake, 1975-80.

Table 2. Average numbers of selective species of fish caught per standard gang gillnet set in 12 Saskatchewan lakes.

Lake	Year	# of Sets	Depth m	Catch							Ref.*
				walleye	Pike	Whitefish	Sauger	Perch	Burbot	Goldeye	
Diefenbaker	1983	34	3-52	25.8	4.9	45.2	1.1	6.1	1.5	14.1	1
Last Mountain	1974	16	5-15	37.1	2.6	15.2	0	52.2	2.0	0	7
Tobin	1979	21	5-20	6.4	2.0	0.1	13.9	1.8	0	13.0	5
Pasqua	1975	5	5-15	86.4	48.6	0	0	1.2	1.2	0	6
Echo	1976	5	5-17	70.4	24.0	15.2	0	28.4	1.0	0	6
Mission	1976	5	5-15	42.2	14.2	19.0	0	46.8	0.6	0	6
Katepwa	1975	5	5-18	27.6	33.0	15.8	0	90.0	1.6	0	6
Crooked	1975	5	5-15	25.6	20.2	0	0	86.6	1.8	0	6
Round	1976	5	5-10	31.0	10.2	0	0	170.2	0.2	0	6
Lac la Ronge	1977	17	3-15	4.4	16.9	11.3	0	13.4	1.6	0	3
Besnard	1973	17	5-16	34.6	11.6	12.8	0	5.6	0	0	4
Pinehouse	1972	21	1-18	41.7	31.1	5.5	2.1	7.4	0	0	2

*Reference: 1-Current study, 2-Chen(1973), 3-Chen(1980), 4-Chen(1974), 5-Durbin(1981), 6-Smith(1977), 7-Smith(1976).

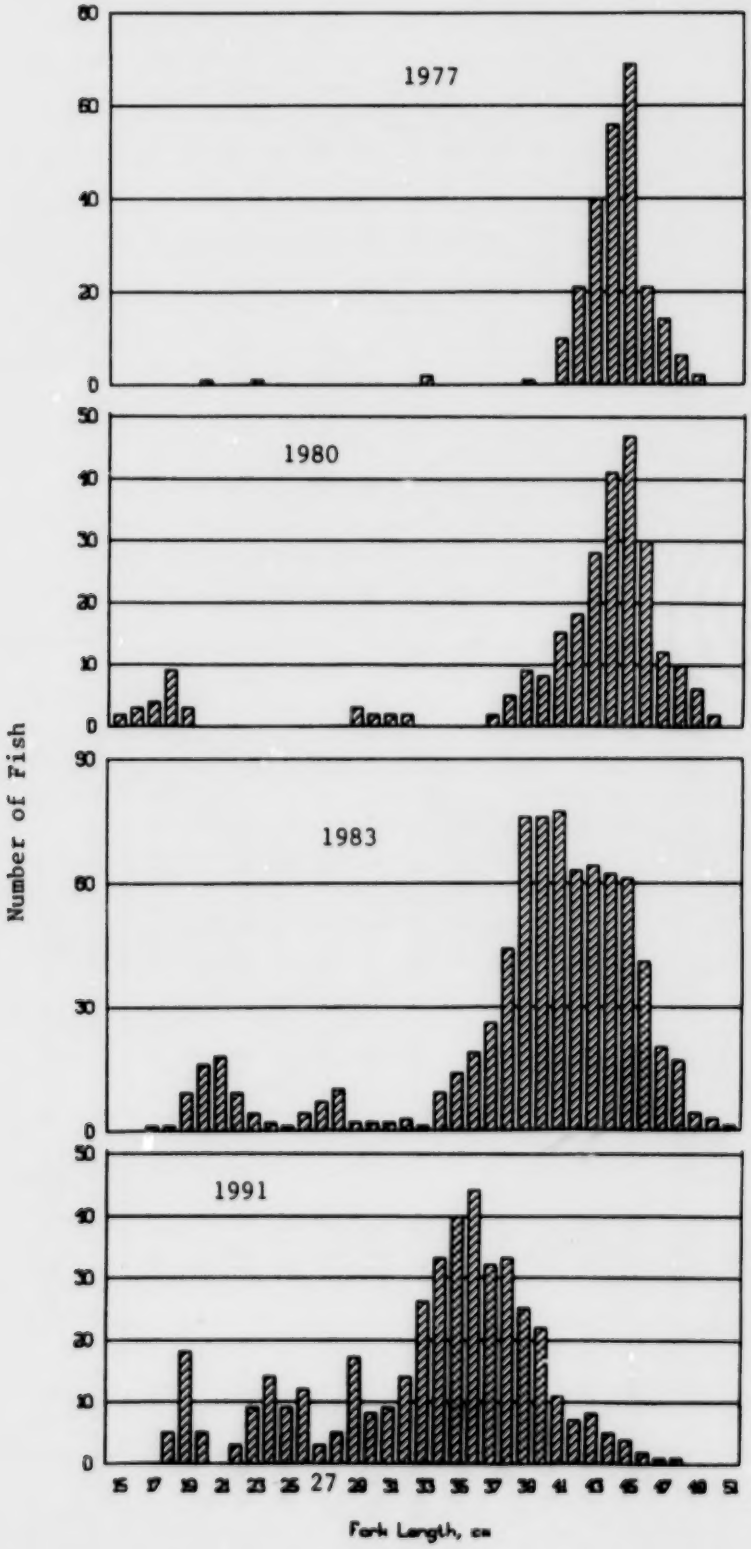


Fig. 9. Length composition of whitefish in the standard gang catches from Lake Diefenbaker in various years.

Fig.7, the catches in the first three years (1967-69) were from the indigenous Saskatchewan River population. Natural reproduction of the population in the lake became evident in 1973, 1974 and 1980 (Fig.8), with the presence of fish in the 15-24 cm range. All fish under 40 cm in length in the standard gang test net catches after 1983 (Fig. 9 and Table 3) were definitely the results of successful natural reproduction.

The extent of winter water draw-downs, ranging from 1.8 m in 1984-85 to 8.55 m in 1973-74 (Table 4), obviously has not seriously devastated whitefish reproduction as previously feared. It appears that the whitefish population has successfully adapted to water fluctuation in the lake, perhaps by reproducing in the substrate below the effects of winter draw-downs.

4.3 DISTRIBUTION AND MOVEMENT

During the period of initial survey, 1967-69, the whitefish population was mainly restricted in the area between Gardiner Dam and Qu'Appelle Arm (Royer 1972a). It is now widely scattered throughout the entire lake, indicated in the 1983 testnetting results (Fig. 10).

The whitefish are mostly concentrated in water below 20 m in the summer months (Table 5) and move toward shallow water near shore in the fall, especially during the spawning season. There is also an extensive lake-wide migration in the post-spawning season, as evidenced from the mark-recapture data (Fig. 11). Out of 17 recaptures, three fish had moved more than 140 km from Saskatchewan Landing to Coteau Bay and Qu'Appelle Arm; two had migrated between 50-110 km downstream. However, a majority of recaptures were made within 15 km from the site of tagging, indicating either slow movement to the summer habitat or returning to the spawning site the following year. Understandably, the number of recaptures reflected various intensities of fishing activity in different locations. Nevertheless, widespread movement and some degree of mixing among breeding stocks are also evident.

5. THE COMMERCIAL FISHERY

In the 10 years of commercial fishing, 1976-85, the annual harvest has fluctuated from a mere 3,963 kg to 112, 741 kg, with an average of 71,165 kg. Fishing effort has varied from 126 to 1,218 units (100 m net/day), averaging 623 units (Table 6). There were only four seasons in which the quota of 90,700 kg was either reached or exceeded. Since it is a fall season fishery aiming at spawning fish, inclement weather conditions have often hampered fishing and disrupted the concentration of spawning fish to a great extent, as were the cases in 1984 and 1985.

Table 3. Percentages of lake whitefish in various size categories, taken with gill nets from Lake Diefenbaker, 1969-91. Also showing the relative numbers of fish per 100 m net.

STANDRAD GANG

	Fork Length, cm						
Year	<20	20-30	30-40	40-45	>45	Total	No./100 m
1969	-	76.2	14.3	9.5	-	21	0.1
1972	-	-	54.0	43.7	2.3	87	3.4
1973	-	7.4	8.4	75.8	8.4	95	1.8
1974	1.7	8.0	15.9	66.4	8.0	113	6.3
1977	-	0.8	1.2	51.4	46.6	244	9.9
1980	0.8	8.1	7.1	41.8	42.2	361	18.8
1983	1.4	9.5	25.4	44.6	19.1	769	16.5
1987	-	9.0	68.6	19.6	2.8	469	39.1
1988	0.5	5.4	61.6	30.9	1.7	354	36.9
1989	0.6	8.0	74.8	14.9	1.7	174	36.3
1991	5.4	18.1	62.1	12.5	1.9	425	39.4
LARGE MESH NETS ONLY (11.4, 12.7 and 14.0 cm)							
1975	-	-	4.9	60.1	35.0	595	15.5
1985	-	-	34.9	49.2	15.9	126	14.3
1986	-	-	36.2	50.0	13.8	116	16.7

Table 4. Magnitude of Lake Diefenbaker winter water draw-down, measured at Gardiner Dam, 1967-85.

Year	Maximum Water Level, m	Minimum Water Level, m	Draw-down m	Draw-down ft
1967-68			4.57	15.0
1968-69			7.01	23.0
1969-70			7.01	23.0
1970-71			8.53	28.0
1971-72			7.62	25.0
1972-73			6.40	21.0
1973-74			8.55	28.1
1974-75			7.01	23.0
1975-76	Oct. : 556.54	Apr. : 549.45	7.09	23.2
1976-77	Oct. : 556.40	Mar. : 549.60	6.80	22.3
1977-78	Oct. : 552.57	Mar. : 547.77	4.80	15.8
1978-79	Oct. : 556.68	Mar. : 550.29	6.39	21.0
1979-80	Oct. : 555.61	Mar. : 549.16	6.45	21.2
1980-81	Oct. : 556.14	Mar. : 551.39	4.75	15.6
1981-82	Oct. : 555.80	Apr. : 547.62	8.18	26.8
1982-83	Oct. : 555.84	Mar. : 549.84	6.00	19.7
1983-84	Oct. : 553.12	Feb. : 549.95	3.17	10.4
1984-85	Oct. : 551.65	Mar. : 549.84	1.80	5.9

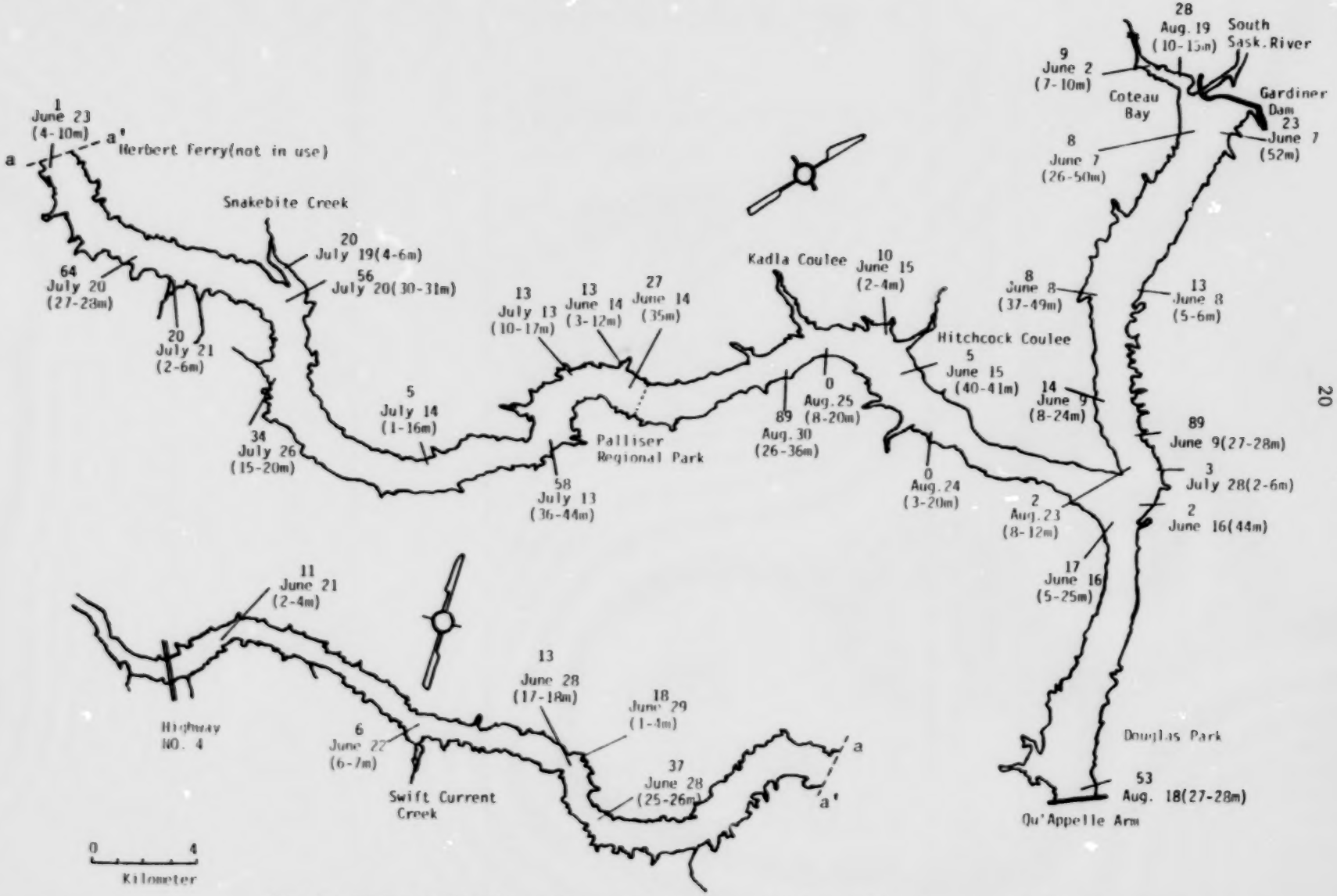


Fig. 10. Numbers of whitefish caught per half standard gang gillnet set at various dates, depths, and locations of Lake Diefenbaker, 1983.

Table 5. Seasonal depth distribution of whitefish in Lake Diefenbaker, as indicated by number of fish per 150 yards of gill net, based on 34 half-gang gillnet sets in June-August, 1983.

Depth (m)	June			July		August	
	1-10	11-20	21-30	11-20	21-31	11-20	21-31
0- 5	13, 14	10	11, 18	20	20, 3	-*	-
6-10	9	13	1, 6	5	-	-	2
11-15	-	17	-	13	-	28	0
16-20	-	-	13	-	34	-	0
21-25	-	-	-	-	-	-	-
26-30	89	-	37	-	56, 64	53	89
31-35	-	27	-	-	-	-	-
36-40	8	-	-	58	-	-	-
41-45	8	5, 2	-	-	-	-	-
46-50	-	-	-	-	-	-	-
>50	23	-	-	-	-	-	-

* No net set.

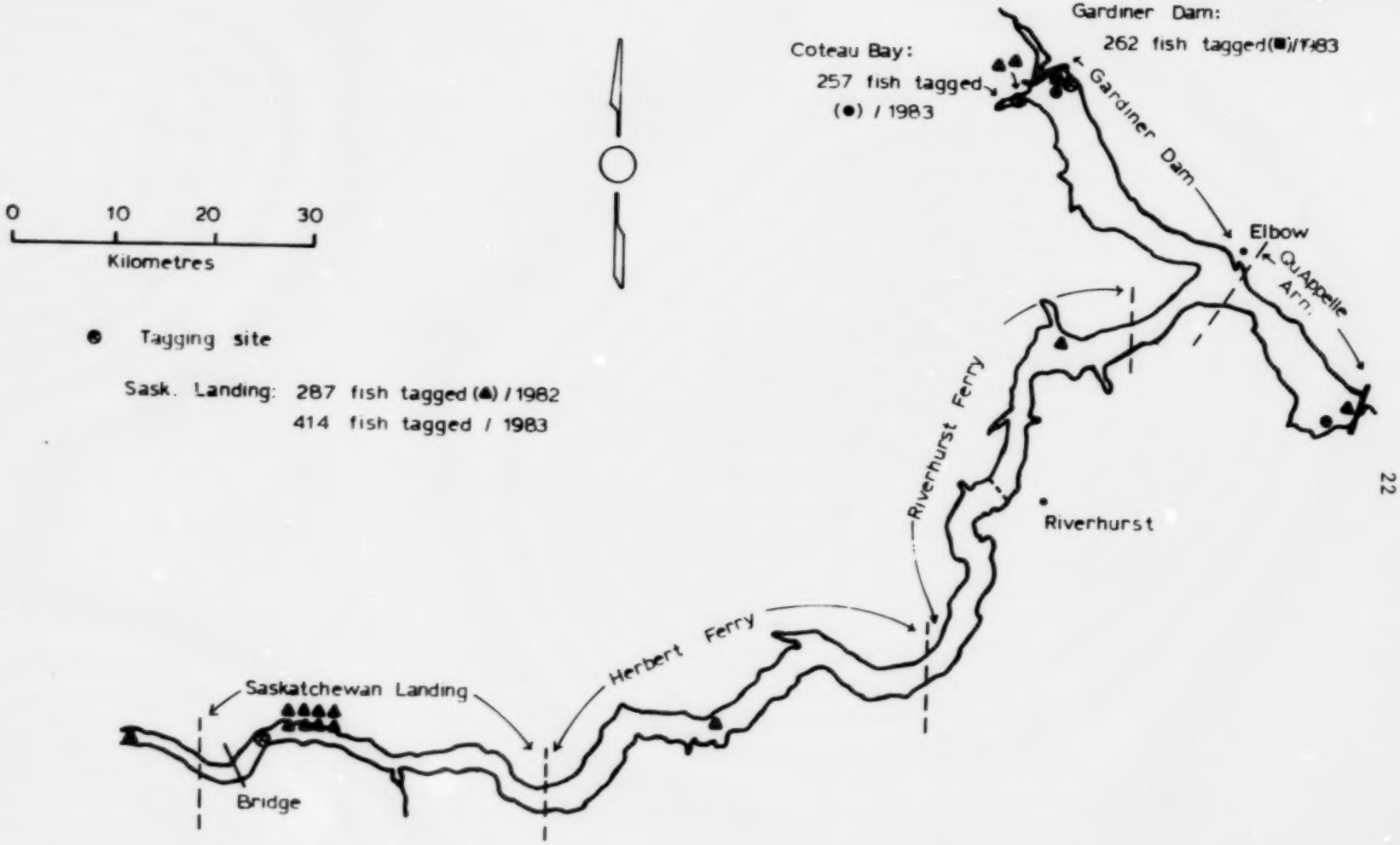


Fig. 11. Locations of tagging 1220 whitefish and 17 recaptures in Lake Diefenbaker, 1982-84.

Table 6. Statistics of the commercial whitefish fishery from the north end (N) and Saskatchewan Landing (S) areas of Lake Diefenbaker, 1976-85.

Year	No. of Lic.*		Ave. m net/day		No. of days fished		Obs. Fishing effort** Catch, kg			(100 m/ day)			CPUE, kg		
	N	S	N	S	N	S	N	S	LAKE	N	S	LAKE	N	S	SUM
1976	2	-	2,000	-	31	-	34,014	-	34,014	620	-	620	55	-	55
1977	3	1	1,900	1,500	22	21	47,636	43,276	90,912	418	315	733	114	137	124
1978	6	3	1,400	1,800	33	42	29,964	44,677	74,674	462	756	1,218	65	59	61
1979	5	3	1,500	1,700	22	17	38,466	46,381	84,847	330	289	619	117	160	137
1980	6	5	1,500	1,800	21	21	37,050	66,277	103,327	315	378	693	118	175	149
1981	6	5	2,000	2,000	14	15	46,774	65,967	112,741	280	300	580	167	220	194
1982	6	5	2,000	2,000	12	17	43,183	57,546	100,729	240	340	580	180	169	174
1983	6	5	2,000	2,000	20	21	32,849	53,839	86.688	400	420	820	82	128	106
1984	8	5	1,800	1,500	5	10	9,492	10,292	19,784	90	150	240	105	69	83
1985	6	-	1,800	-	7	-	3,963	-	3,963	126	-	126	31	-	31

* Licenses

** Observed fishing effort

5.1 THE CATCH

Figure 12 shows the length frequency distributions of whitefish in commercial samples. The fishery harvests chiefly fish in the 43-47 cm range, because of the use of the 14.0 cm mesh net which is most effective toward fish of this length range (Fig. 13). The age frequency distribution of the catches is shown in Fig. 14. Noticeable decreases both in the mean length and mean age of the commercial catch began in 1982 and persisted until 1985. This is due to the fact the whitefish population has been gradually depleted of the larger and older age groups since 1981, as shown in Table 3 and Fig. 15, in which the standard gang catches from all the years are grouped in five size categories. As early as in 1977 and 1980, fish larger than 45 cm comprised a significant portion of the test net catches. Beginning in 1983, the >45 cm group began to diminish, and so did the 40-45 cm group a few years later. The fish that are susceptible to the commercial fishing net in Lake Diefenbaker, mainly >45 cm and 40-45 cm to a lesser extent, are no longer present in quantities which sustained the harvest in the first half of the commercial fishery. On the other hand, the proportion of fish under 40 cm has increased significantly at the same time, indicating the new recruits have become relatively more abundant and vulnerable to fishing as older and larger fish are gradually trimmed off the population.

There are apparently two distinct types of whitefish in the lake, distinguishable by their body contours: humpback and slender forms (Fig. 16). The 14-cm (5.5 in) mesh net used in the fishery is undoubtedly more selective toward the humpback fish, which as a result have become noticeably fewer in number in the last few years of fishing, according to the lake fishermen. It is not known if these two forms represent the respective indigenous and stocked fish.

5.2 CATCH PER UNIT OF FISHING EFFORT

The catch per unit of fishing effort (CPUE) in terms of 100 m net/day has varied from 31 kg in 1985 to 194 kg in 1981 (Table 6 and Fig. 17). Initially as most fishermen were inexperienced in reservoir fishing, unaware of fish distribution pattern and movement, such a wide variation in CPUE is normal in a young fishery. It should be noted that the fishing effort mentioned here is the "observed fishing effort", which is different from the "effective fishing effort" as used Section 6 for the estimation of the parameters of the catchable stock.

The south end fishery has usually been more productive than its north-end counterpart. This is because : 1) the average size of fish caught in the former is slightly larger; 2) a heavier concentration of fish in a much narrower area in the Saskatchewan Landing area; and 3) the fishing operation in the north end is more vulnerable to inclement weather due to a wider, open water.

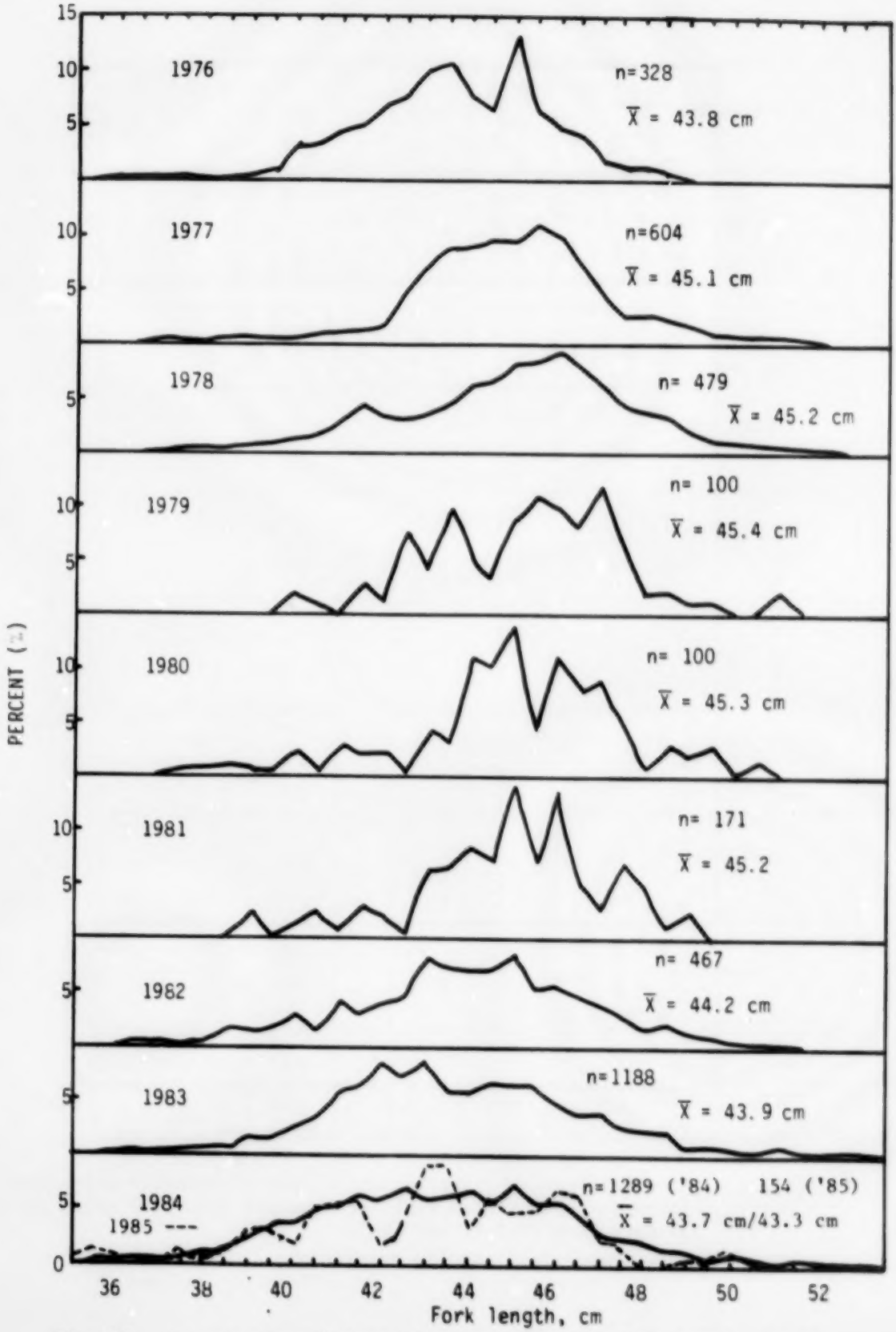


Fig. 12. Length compositions of commercial whitefish samples from Lake Diefenbaker, 1976-85.

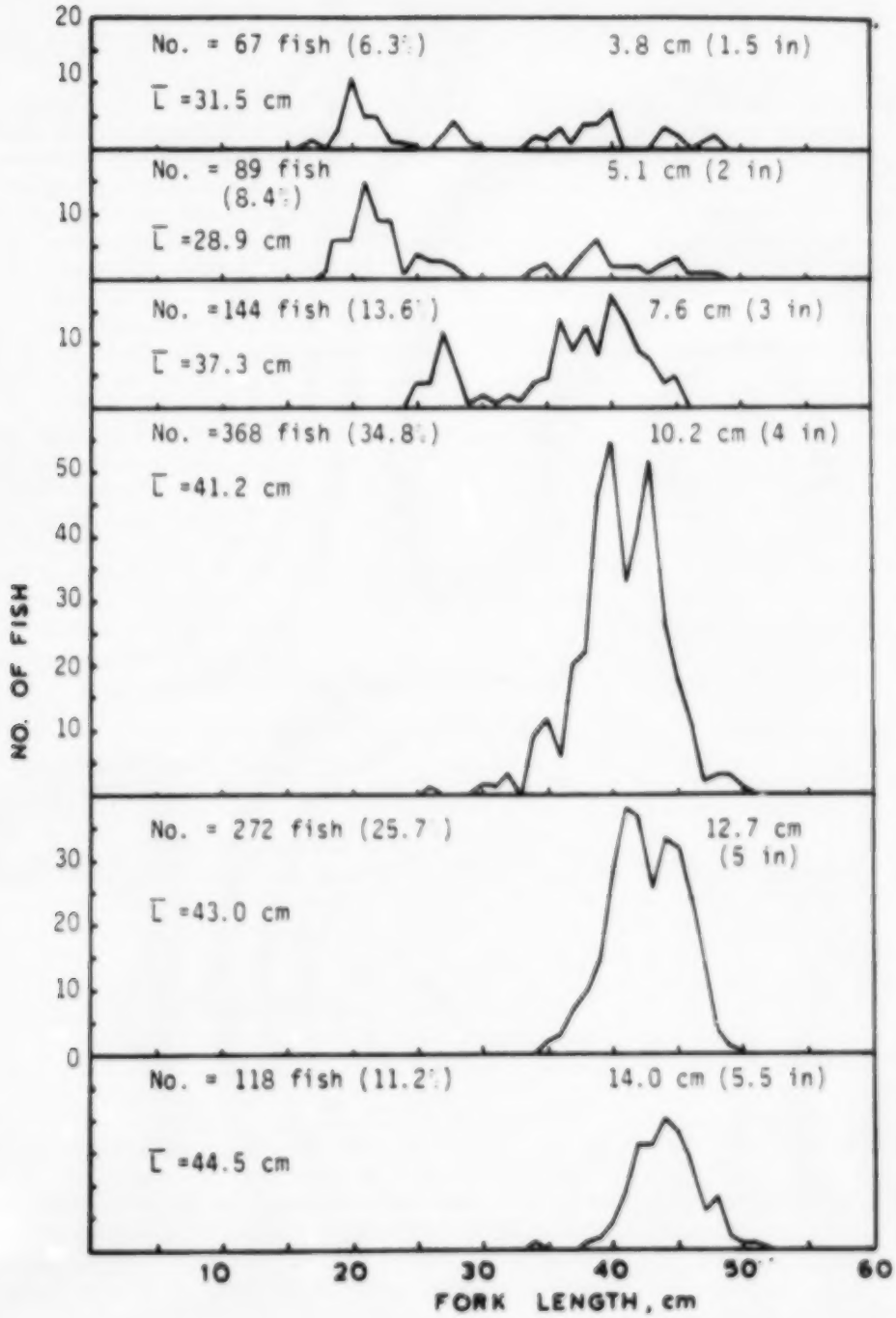


Fig. 13. Length-frequency distribution of Lake Diefenbaker whitefish taken in various mesh sizes of standard gang gill nets, based on data from 1967-74 and 1983.

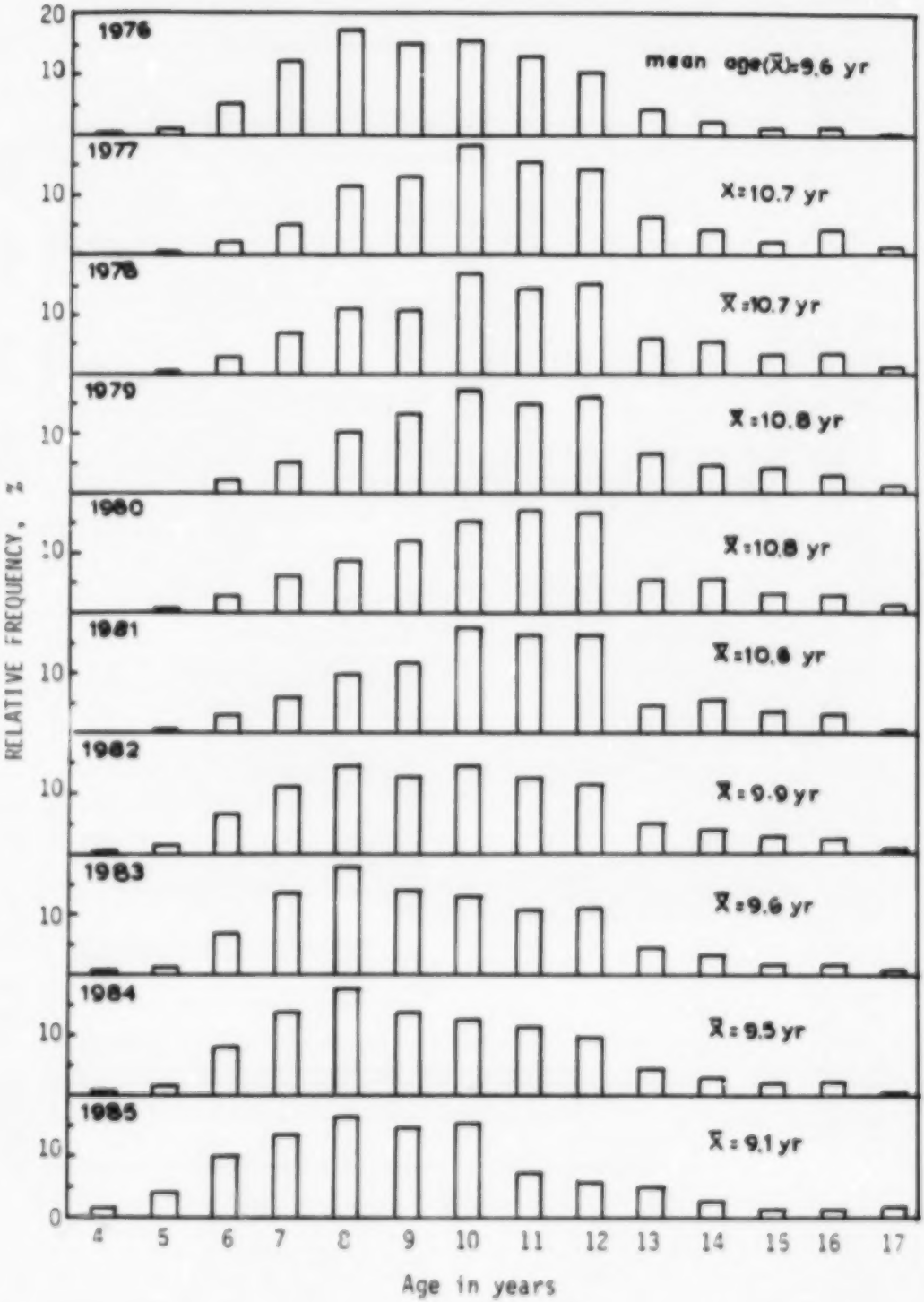
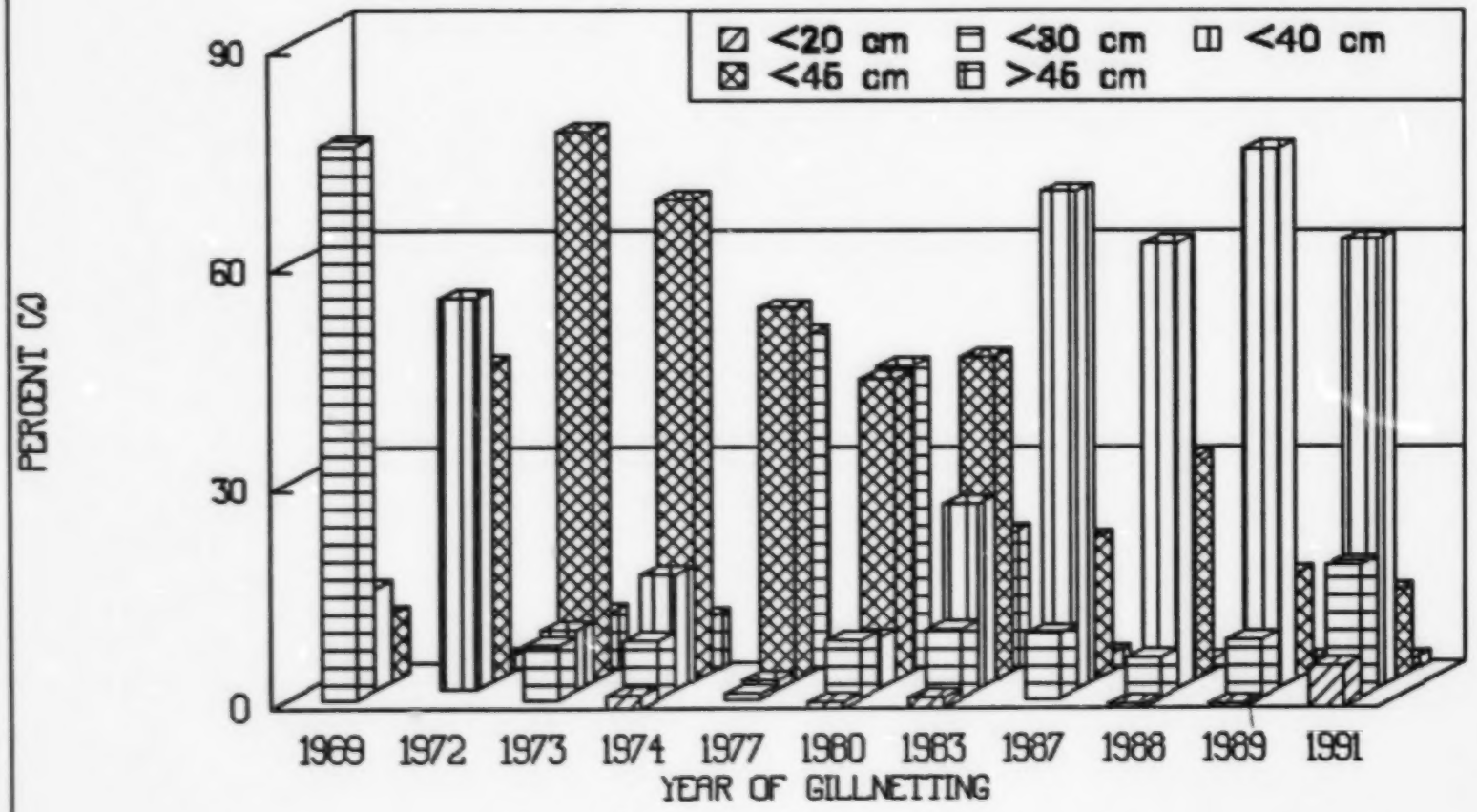


Fig. 14. Relative age composition of Lake Diefenbaker whitefish commercial samples, 1976-85.

Fig. 15. PERCENTAGES OF LAKE DIEFENBAKER WHITEFISH IN FIVE SIZE GROUPS IN THE STANDARD GANG GILLNET CATCHES, 1969-1991.



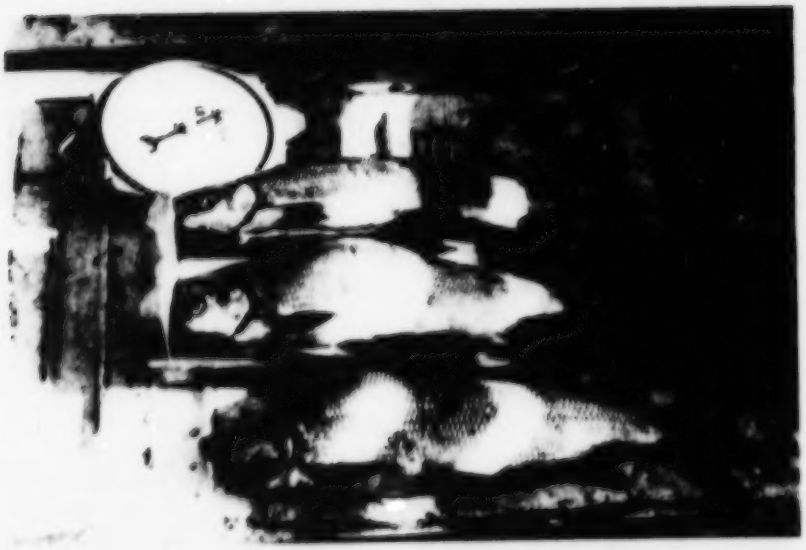


Fig. 16. Lake Diefenbaker whitefish from the commercial catch, showing two distinct body forms : slender and humpback.

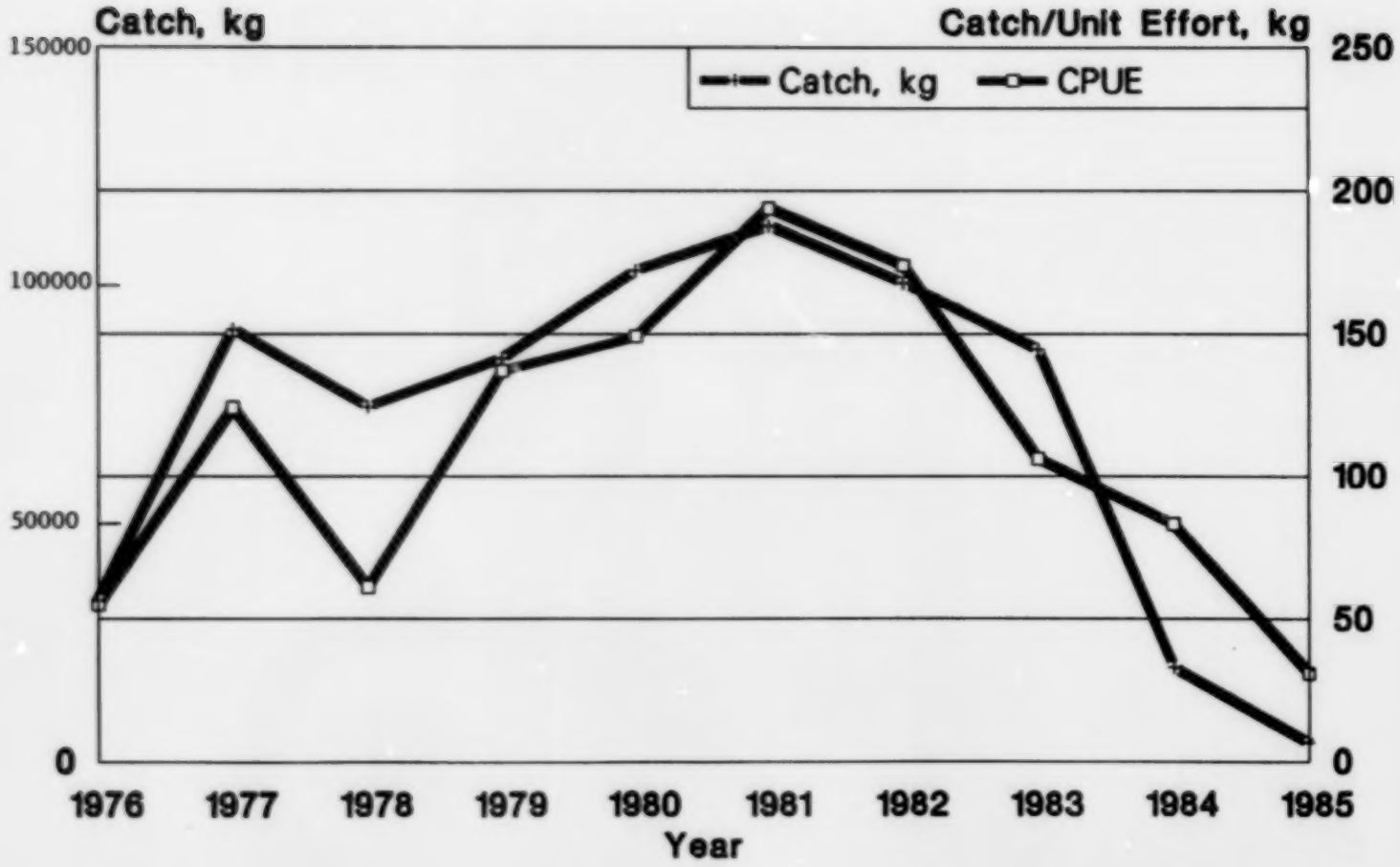


Fig. 17. Total catch and catch per unit of fishing effort (CPUE) of whitefish from the Lake Diefenbaker commercial fishery, 1976-85.

5.3. EFFECT OF GILLNET SELECTIVITY

Figure 18 shows the size composition of whitefish taken by gill nets of larger meshes in the standard gang set. Clearly, the 10.2 cm mesh is most effective in catching whitefish in Lake Diefenbaker (also see Fig. 13). The legal mesh net, 14.0 cm, is selective toward fish in the 34-53 cm range, but is most efficient for fish between 43 and 47 cm. Compared to the 10.2 cm mesh net, the commercial mesh is only about one-third as effective in harvesting the whitefish population in the lake, in terms of number, or only 40% as effective in terms of total weight harvested.

5.4 SEX RATIO AND MATURITY

The sex ratio of fish in the commercial catch, based on 2,051 specimens examined in 1983 and 1984, was 57% vs 43% in favour of females. This is likely due to the fact that females are heavier than males, especially during the fall spawning season in which commercial fishing takes place, thus more susceptible to 14.0 cm mesh nets.

About 46% of the female fish in the commercial catch were in spawning condition, 53% were non-spawning mature fish and only 1% were immature fish. A great majority of males were in spawning condition. There were also a few senile fish of both sexes in the catch.

6. POPULATION ASSESSMENT

The population assessment is based on 1) the results from the mark-recapture study conducted in 1982-84 and 2) data of the 10 years commercial sampling. Since commercial fishing is the only significant exploitation of the whitefish population, the estimated population parameters in this section are relevant only to the catchable stock which is vulnerable to 14.0 cm mesh nets, i.e. fish 34 cm and larger.

6.1 THE MARK-RECAPTURE STUDY

A total of 1220 whitefish were tagged and released alive, 287 fish in 1982 and 933 in 1983. In the years following tagging, eight fish were recaptured in 1983 and nine in 1984. The survival rate of the marked fish between 1982 and 1984 is estimated at 0.41 (Table 7). The mark-recapture study is considered to have two independent components, 1982 tagging - 1983 commercial fishing, and 1983 tagging - 1984 fishing. That is, the 1982 marked fish were only considered in the 1983 commercial fishery but excluded in 1984.

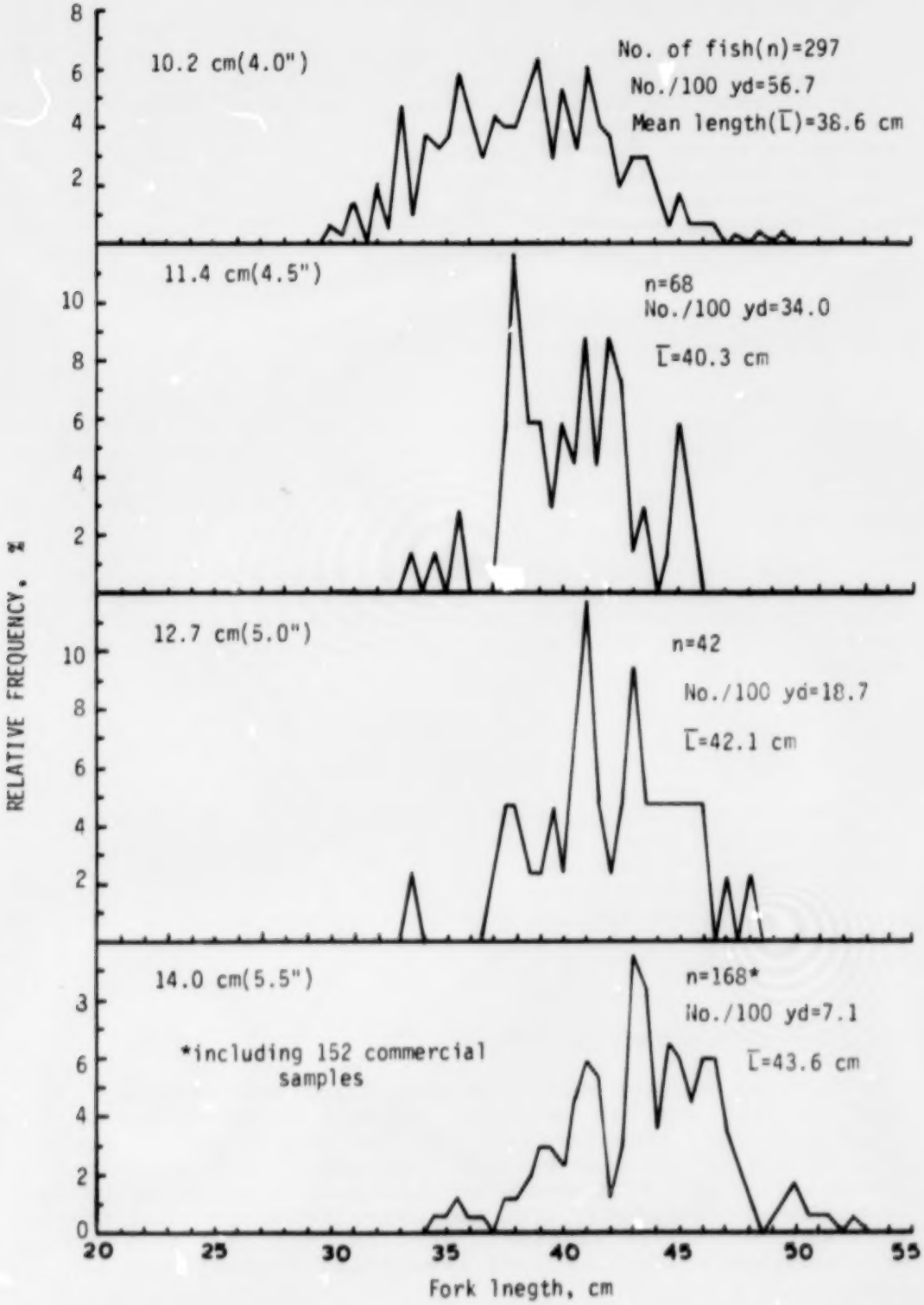


Fig. 18. Length frequency distribution of Lake Diefenbaker whitefish taken with various mesh nets, Oct.30-Nov.14, 1985.

Table 7. Estimating the survival rate of marked whitefish in Lake Diefenbaker between 1982 and 1984.

Year	No. of fish marked (M)	No. of fish recaptured 1983	1984
1982	M_1 = 287	R_{11} = 8	R_{12} = 1
1983	M_2 = 933		R_{22} = 8

$U_2 = R_{22}/M_2$

$U_2 = R_{12}/M_{12}$

$M_{12} = R_{12}/U_2$

$S = M_{12}/M_1 = R_{12} \times M_2 / R_{22} \times M_1$

$= 1 \times 933 / 8 \times 287$

$= 0.41$

M_1 : no. of fish marked in the first year (1982)

M_2 : no. of fish marked in the second year (1983)

R_{11}: recapture of the first year marked fish in the first year fishing

R_{12}: recapture of the first year marked fish in the second year fishing

R_{22}: recapture of the second year marked fish in the second year fishing

M_{12}: no. of fish marked in 1982 remained alive in 1983

S: survival rate

6.1.1 1982 Tagging - 1983 Commercial

1. Among the 287 tagged fish, an estimated 36.8% were not susceptible to commercial fishing because of their small size (Fig. 19), leaving only 182 fish vulnerable to the fishery (287 x 0. 63.2%).

2. Furthermore, the survival of these tagged fish was estimated at 41% in one year (Table 7), leaving only 75 fish (M) remaining alive and susceptible to commercial fishing in 1983.

3. The total number of whitefish harvested in 1983 commercial fishing was 73,464 (C), which was derived from total weight of harvest divided by average weight of fish.

4. Total number of the 1982 marked fish recaptured in the 1983 season was 8 (R).

5. Total number of the catchable stock (N) in 1983 was:

$$N = (M + 1) \times (C + 1)/ (R + 1) \quad .....(1)$$
$$= 76 \times 73,465 / 9$$
$$= 620,371$$

6. Rate of fishing (F) in 1983 was:

$$F = C/N \quad ..... \quad (2)$$
$$= 73,464 / 620,371$$
$$= 0.1184$$

7. Coefficient of catchability* (q) was:

$$q = F/f = C/f \times 1/N \quad ..... \quad (3)$$
$$= 0.1184 / 820$$
$$= 0.000144 \qquad \text{(where f is fishing effort)}$$

(* the proportion of the catchable stock caught by one unit of fishing effort)

6.1.2 1983 Tagging - 1984 Commercial Fishing.

1. Among the 933 marked fish, only 72 % or 672 fish were susceptible to commercial fishing (Fig. 20).

2. Adapting the 41% survival rate to the susceptible fish means only 276 fish (672 x 41%) remained alive in the 1984 season (M).

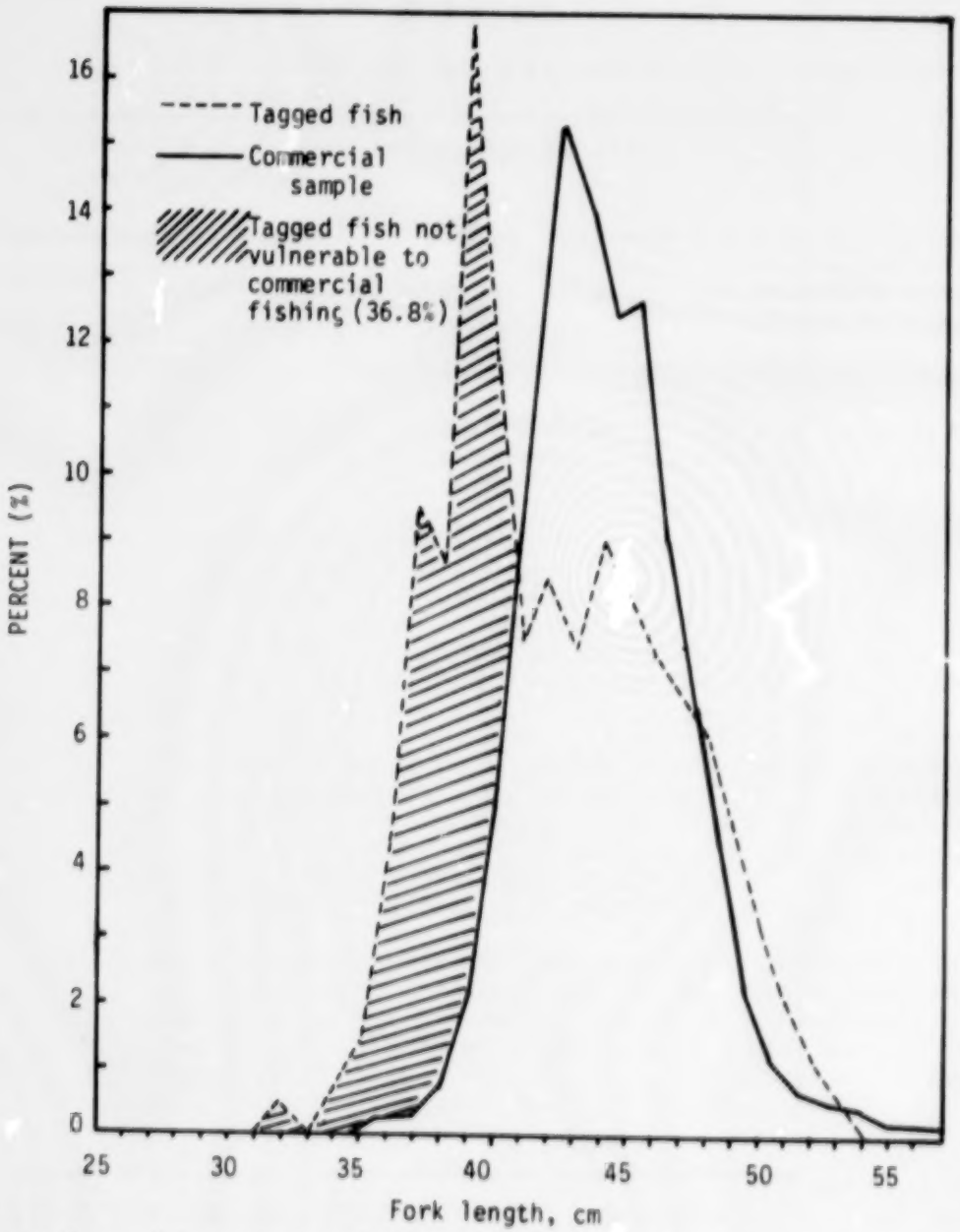


Fig. 19. Comparison of length compositions between the tagged fish and commercial sample, Lake Diefenbaker. Based on the 1982 tagging and 1983 commercial sampling data.

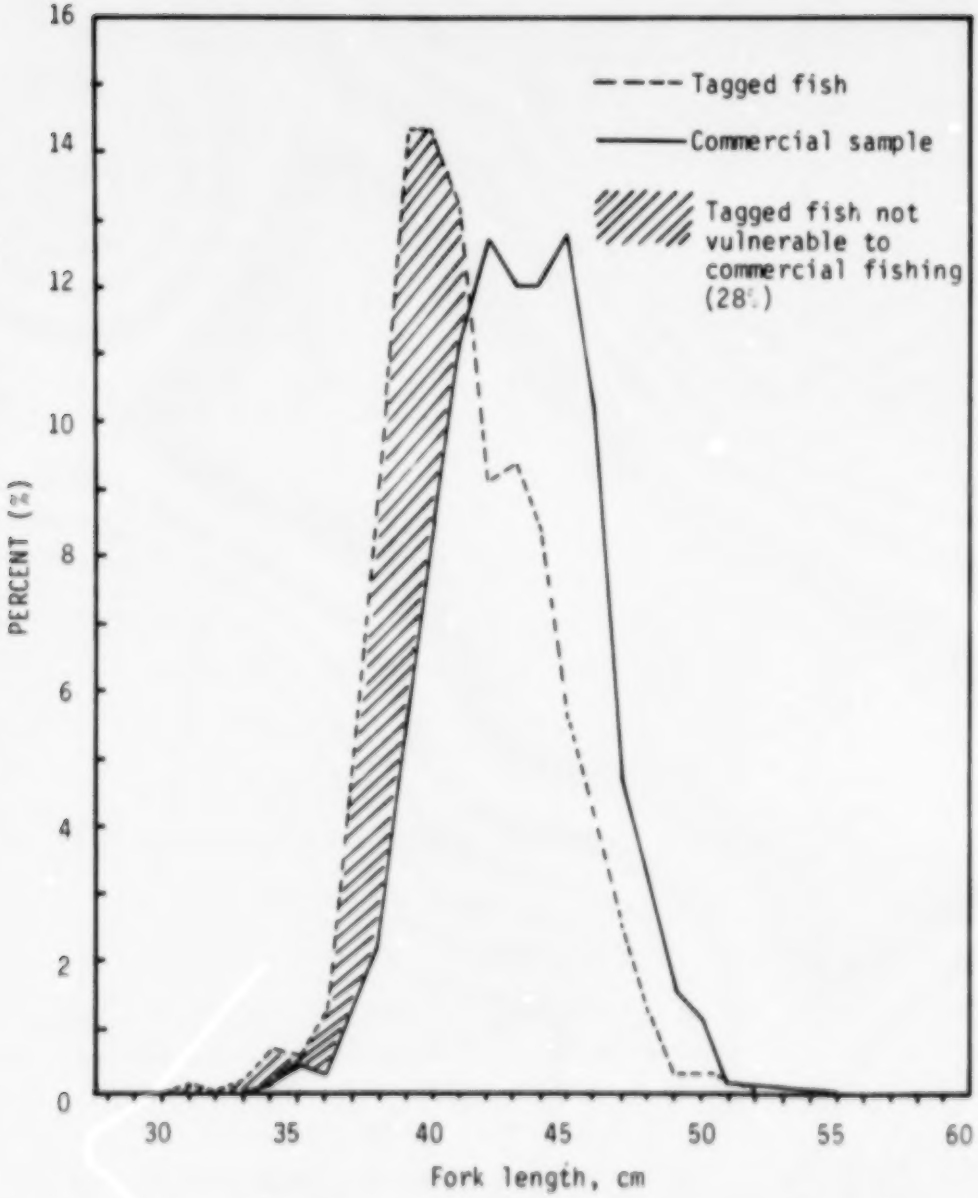


Fig. 20. Comparison of length compositions between the tagged fsih and commercial sample, Lake Diefenbaker. Based on the 1983 tagging and 1984 commercial sampling data.

3. Total number of whitefish harvested in 1984 was calculated at 17,373 (C).

4. Total number of the 1983 marked fish recaptured in 1984 was 8.

5. Total number of catchable stock (N) in 1984 was 534,702.

6. Rate of fishing (F) in 1984 was 0.0324.

7. Coefficient of catchability (q) was 0.000135.

6.1.3 Conclusion from The Mark-Recapture Study.

1. The catchable stock of fish 34 cm and larger has decreased 13.8% from 620,371 in 1983 to 534,702 in 1984.

2. Rate of fishing (F) or instantaneous rate of fishing mortality was low in both years, considering the size of the available stock in the lake. This is because the 14.0 cm legal mesh net is not effective in harvesting fish under 40 cm, whose number has increased significantly since the early 1980s.

3. The proportion of catchable stock caught per unit of fishing effort (q) or catchability coefficient also decreased slightly from 1983 to 1984, in conjunction with the decrease in the catchable stock. This indicates a slightly poor fishing efficiency in light of a decreased stock.

4. With the evidence showing strong recruitment and proliferation of fish under 40 cm, the significant decrease in the catchable stock is undoubtedly the results of selective depletion of fish over 40 cm, especially those over 45 cm , by the 14.0 cm mesh gill nets in the commercial fishery.

6.2 VIRTUAL POPULATION (UTILIZED STOCK) ANALYSIS

The virtual population or utilized stock is defined as the total numbers of fish in a year class that are harvested by the fishery during its entire life span (Fry 1949) or the "sum of catches from a particular year-class during the years it contributes to the fishery" (Ricker 1975). The virtual population represents the minimum estimate of a year-class at the time it has just become vulnerable to the fishery, and is not the true number

of population of each year-class.

Cohort analysis, which traces through various year-classes from the time each year-class enters the fishery to the time it completely disappears from the lake, was used to estimate the virtual population. Since the analysis is based on the fish that are actually harvested by the fishery, the estimated population parameters are more relevant to fish over 45 cm in length which make up the greatest proportion in the commercial catch. As such, the interpretation of the analysis results in the following section differs greatly from that based on the mark-recapture results. The latter cover a wider range of the catchable stock, including a larger portion of fish under 40 cm.

6.2.1 Cohort Analysis - Estimation of population parameters.

Table 8 shows the commercial fishing statistics, including the age compositions of the catches. The total numbers of fish were obtained from averaging the total harvests in weight by the mean weight of fish in each year, and the age compositions in the yearly catches were extrapolated from the 1985 otolith ageing results.

The age composition of the catch (C) is further arranged according to the year-classes and ages at which these fish enter the fishery and subsequently caught, the virtual population (VP). This is done by summing up diagonally all fish in a year-class at various ages at which they were subsequently harvested (Table 9):

$$VP_y = \sum^{k} C_{ij} \quad \ldots\ldots\ldots (4)$$

where y = year-class
i = age group
j = fishing season
k = maximum age of the year-class in the catch

Next the age-specific exploitation rate (U) is calculated from the equation:

$$U_{ij} = C_{ij} / \sum^{k} C_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

As stated earlier, these are the maximum rates of exploitation (U_{max}), as the calculation is based only on the fish that are actually harvested by the fishery. A mean maximum exploitation rate is obtained for each fishing season (Table 10), and converted into maximum estimates of fishing mortality (F_{max}) from the following relation:

$$U = 1 - \exp(-F) \quad \ldots\ldots\ldots\ldots (6)$$

The maximum estimated catchability (q_{max}), or an index of q, in each year is obtained from the equation $q = F/f$, where f is observed fishing effort.

Table 8 . Age composition of Lake Diefenbaker whitefish in the commercial catch, 1976- 85.

Year	No. of Fish	Fishing Effort	No. of fish in each age group													
			4	5	6	7	8	9	10	11	12	13	14	15	16	17
1976	23786	620*	48	214	1284	2878	4163	3615	3758	3068	2474	1022	595	287	309	71
1977	57540	733	46	213	1312	3119	6588	7584	10484	9016	8326	3752	2630	1277	2382	811
1978	51124	1218	51	210	1580	3533	5537	5490	8768	7275	7914	3144	2991	1876	1968	787
1979	53363	619	-	37	1153	2738	5406	7177	9232	8054	8564	3607	2625	2220	1750	800
1980	72766	693	109	458	2067	4417	6396	8768	11257	12654	12312	4215	4227	2379	2270	1237
1981	82898	580	58	406	2594	4966	8066	9815	14764	13803	13645	4023	4500	3050	2868	340
1982	87591	580	306	1366	5527	9433	12658	11250	12650	11089	10011	4526	3512	2435	2137	691
1983	73465	820	235	830	5003	9925	13150	10278	9631	7986	7596	3313	2366	1418	1256	478
1984	17203	240	90	310	1390	2386	2963	2327	2100	1878	1650	740	538	365	387	79
1985	3603	126	47	142	356	474	593	521	545	261	213	190	95	48	48	70

* 100 m net/night

Table 9. Virtual population of Lake Diefenbaker whitefish of various year-classes at the ages they enter the fishery.

Year Class	Age Groups													
	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1959														71
1960													1120	811
1961												3456	3169	787
1962											4640	4045	2768	800
1963										8515	7493	4863	2987	1237
1964									14047	11573	7821	4830	2610	340
1965								23101	20033	11707	8563	5938	3559	691
1966							34187	30429	21413	13499	9892	5665	2615	478
1967						42423	38808	28324	21049	12485	8270	3770	1335	79
1968					50291	46128	38544	29776	21722	9410	5387	1875	457	70
1969				57792	54914	48326	42836	33604	20950	7305	2779	413	48	
1970			56087	54803	51684	46147	38970	27713	13910	3899	586	48		
1971		53517	53303	51991	48458	43052	34284	19520	8431	835	95			
1972	43266	43218	43005	41425	38687	32291	22476	9826	1840	190				
1973	36864	36818	36608	35455	31038	22972	11722	2091	213					
1974	32418	32367	32330	30263	25297	12639	2361	261						
1975	28507	28507	28049	25455	16022	2872	545							
1976	19451	19342	18936	13409	3484	521								
1977	9406	9348	7982	2979	593									
1978	3000	2694	1864	474										
1979	901	666	356											
1980	1133	142												
1981	47													

Table 10. Annual age-specific exploitation rate (U) and maximum exploitation rate (Umax) for the Lake Diefenbaker whitefish commercial fishery.

	Age-specific Exploitation Rate (U)													
Year	4	5	6	7	8	9	10	11	12	13	14	15	16	Umax*
1976	.0011	.0040	.0229	.0498	.0828	.0852	.1099	.1328	.1761	.1200	.1282	.0830	.2759	.1327
1977	.0012	.0049	.0246	.0569	.1200	.1644	.2702	.2963	.4156	.3242	.3510	.3157	.7517	.3343
1978	.0016	.0057	.0367	.0679	.1071	.1136	.2275	.2569	.3696	.2686	.3824	.3858	.7110	.3136
1979	-	.0011	.0315	.0661	.1116	.1555	.2155	.2705	.4069	.2672	.3065	.4596	.5859	.3088
1980	.0056	.0161	.0639	.1246	.1653	.2037	.2888	.3765	.5668	.3376	.4273	.4006	.8697	.4041
1981	.0062	.0210	.0925	.1641	.2599	.3035	.4306	.4981	.6513	.4275	.5441	.5384	.8058	.4955
1982	.102	.1461	.2919	.3705	.5004	.4892	.5376	.5681	.7197	.6196	.6519	.6459	.8172	.6166
1983	.2607	.3081	.6267	.7402	.8207	.8091	.7622	.7341	.9010	.8497	.8514	.7562	.9408	.8250
1984	.3865	.4651	.7454	.8008	.8504	.7937	.6400	.6252	.5704	.8862	.9181	.8838	.8468	.7794

* Umax = (sum of U)/ no. of year

Since we have found from Table (8) that an increase in the observed fishing effort does not always result in corresponding increase in the harvest (in fact the two are rather irregularly correlated), the observed fishing effort must be adjusted to units of effective fishing effort. The adjusted effective fishing effort is such that an increase in one unit of effort cause a proportional increase in fishing mortality, F, (Ricker 1975).

Table 11 lists the adjustment of effective fishing effort (f_2) from observed fishing effort (f_1). First of all, the calculated index of catchability (q_{max}) in each year is converted into relative catchability (q_{rel}). The highest q_{rel} in 1984 is 27 times more than that in 1976, indicating that each unit of effective fishing effort in 1984 caused 27 times higher fishing mortality to the existing catchable stock than in 1976. Next the effective fishing effort in each year is derived from multiplying the observed effort with the corresponding q_{rel}.

6.2.2 Assessment of stock-catch relationship.

With the effective fishing effort and age composition of catch in each year known, the age-specific rate of instantaneous total mortality rate (Z_{ij}) can be derived from the following equation:

$$Z_{ij} = \log_e (C_{ij} / f_j) - \log_e (C_{i+1,\ j+1} / f_{j+1}) \quad \ldots\ldots\ (7)$$

where Z_{ij} = age-specific instantaneous total mortality rate for age i fish in year j.

C_{ij} = the number of age i fish caught in year j.

f_j = effective fishing effort in year j.

Since age-groups in the fishery are not fully vulnerable until at age 8 and the numbers of fish often become negligible after age 16, the estimated age-specific instantaneous total mortality rates are therefore based on ages 8-16 fish only (Table 12). Each Z_i is then weighed by the inverse of the standard deviation of Z_i's for all years. This, according to Schaaf and Huntsman (1976), gives "the most weight to the age-specific mortality rate which is least affected by fluctuating year-class strength." The instantaneous natural mortality (M) and catchability coefficient (q) are then estimated from the regression of Z_i's against their corresponding effective fishing efforts, f's:

$$Z = 0.3403 + 0.00565\ f \quad \ldots\ldots\ldots\ldots\ (8)$$

The intercept (0.3403) is equivalent to M and the slope (0.00565) is the catchability coefficient (q). The rate of fishing or instantaneous fishing mortality (F) is then obtained from the equation :

$$F = q \times f_2. \quad \ldots\ldots\ldots\ (9)$$

Table 11. Adjustment of fishing effort from the relative coefficient of catchability (q). Lake Diefenbaker commercial whitefish fishery, 1976-85.

Year	Umax	Fmax	q(max)	q(rel)	Observed effort, f_1	Effective effort, f_2
1976	.1317	.1423	.00023	.03645	620	22.60
1977	.3343	.4070	.00056	.08816	733	64.62
1978	.3136	.3763	.00031	.04906	1218	59.75
1979	.3088	.3693	.00060	.09474	619	58.64
1980	.4041	.5176	.00075	.11860	693	82.19
1981	.4955	.6842	.00118	.18733	580	108.60
1982	.6166	.9587	.00165	.26248	580	152.20
1983	.8250	1.7432	.00213	.33756	820	276.80
1984	.7794	1.5114	.00630	1.00000	240	240.00
1985*	.3526*	.4347	.00345	.5476	126	69.00

* Extrapolated from the data set covering 1976-84:

$$U_{max} = 0.3449 + 0.000002 \text{ Catch}$$

Table 12. Age-specific instantaneous total mortality (Z_{ij}) and weighed instantaneous total mortality rate (Z) against the inverse of the standard deviation (SD) of the age-specific rate. Lake Diefenbaker commercial whitefish fishery, 1976-85.

Year	Age-specific Instantaneous Total Mortality rate (Z_{ij})									Weighed Z	Effective Effort	F*
	8	9	10	11	12	13	14	15	16			
1976	-.4324	-.8973	-.7080	-.8309	-.2490	-.7778	-.5963	-1.949	-.7975	-.7608	22.6	0.128
1977	.6901	.3628	.8732	.6382	1.4817	.7345	.8457	.0753	1.6153	.8291	64.6	0.365
1978	-.9363	-1.197	-.592	-.8400	.1089	-.4964	-.3788	-.6073	.2233	-.5272	59.8	0.337
1979	-.3707	-.3372	-.2020	-.3115	.8218	-.0457	.2113	.0906	.4599	.0396	58.6	0.331
1980	-.6062	-.6991	-.3820	-.2534	.9405	-.2434	.1484	-.3649	1.7206	.0201	82.2	0.464
1981	-.3327	-.2537	.2862	.3212	1.1035	.1358	.6141	.3557	1.4232	.3942	108.6	0.614
1982	.5546	.5017	.8062	.7246	1.4521	.9949	1.2532	1.0083	1.8438	1.0049	152.2	0.860
1983	.5032	.3594	.4061	.3483	1.1001	.5891	.6404	.0699	1.5376	.6242	276.8	1.554
1984	1.0939	.8072	1.4410	1.5323	1.5171	1.4084	1.7723	1.3843	1.0656	1.3363	240.0	1.356

* Rate of fish or instantaneous fishing mortality.

Table 13. Computed effective fishing effort (f_2), catch per unit effort (CPUE), rate of fishing (F), mean stock size (B), and equilibrium yield (Y_e). Lake Diefenbaker commercial whitefish fishery, 1976-85.

Year	Catch (no)	f_2	CPUE	F	Stock Size (B) (no)	Stock Size (B) (kg)	ΔB* (no)	Y_e (no)
1976	23,786	22.60	1,052	0.128	186,265	266,359		
1977	57,540	64.62	890	0.365	157,595	248,999	-17,415	40,125
1978	51,124	59.75	856	0.338	151,435	221,095	1,727	52,851
1979	53,363	58.64	910	0.331	161,049	256,068	2,630	59,762
1980	72,766	82.19	885	0.464	156,695	222,507	-13,004	55,466
1981	82,898	108.65	763	0.614	135,040	183,655	-27,432	55,466
1982	87,591	152.24	575	0.860	101,831	117,106	-44,032	43,559
1983	73,465	276.80	265	1.564	46,975	55,431	-44,572	28,893
1984	17,203	240.00	72	1.356	12,687	14,590	-20,283	-3,080
1985	3,603	69.49	52	0.390	9,243	10,167		

* $\Delta B = (B_3 - B_1)/2$

$Y_e/f_2 = 1013 - 3.8628\ f_1 \quad (r = 0.93)$

Table 12. Age-specific instantaneous total mortality (Z_{ij}) and weighed instantaneous total mortality rate (Z) against the inverse of the standard deviation (SD) of the age-specific rate. Lake Diefenbaker commercial whitefish fishery, 1976-85.

Year	Age-specific Instantaneous Total Mortality rate (Z_{ij})									Weighed Z	Effective Effort	F*
	8	9	10	11	12	13	14	15	16			
1976	-.4324	-.8973	-.7080	-.8309	-.2490	-.7778	-.5963	-1.949	-.7975	-.7608	22.6	0.128
1977	.6901	.3628	.8732	.6382	1.4817	.7345	.8457	.0753	1.6153	.8291	64.6	0.365
1978	-.9363	-1.197	-.592	-.8400	.1089	-.4964	-.3788	-.6073	.2233	-.5272	59.8	0.337
1979	-.3707	-.3372	-.2020	-.3115	.8218	-.0457	.2113	.0906	.4599	.0396	58.6	0.331
1980	-.6062	-.6991	-.3820	-.2534	.9405	-.2434	.1484	-.3649	1.7206	.0201	82.2	0.464
1981	-.3327	-.2537	.2862	.3212	1.1035	.1358	.6141	.3557	1.4232	.3942	108.6	0.614
1982	.5546	.5017	.8062	.7246	1.4521	.9949	1.2532	1.0083	1.8438	1.0049	152.2	0.860
1983	.5032	.3594	.4061	.3483	1.1001	.5891	.6404	.0699	1.5376	.6242	276.8	1.554
1984	1.0939	.8072	1.4410	1.5323	1.5171	1.4084	1.7723	1.3843	1.0656	1.3363	240.0	1.356

* Rate of fish or instantaneous fishing mortality.

Table 13. Computed effective fishing effort (f_2), catch per unit effort (CPUE), rate of fishing (F), mean stock size (B), and equilibrium yield (Y_e). Lake Diefenbaker commercial whitefish fishery, 1976-85.

Year	Catch (no)	f_2	CPUE	F	Stock Size (B) (no)	Stock Size (B) (kg)	ΔB* (no)	Y_e (no)
1976	23,786	22.60	1,052	0.128	186,265	266,359		
1977	57,540	64.62	890	0.365	157,595	248,999	-17,415	40,125
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1983	73,465	276.80	265	1.564	46,975	55,431	-44,572	28,893
1984	17,203	240.00	72	1.356	12,687	14,590	-20,283	-3,080
1985	3,603	69.49	52	0.390	9,243	10,167		

* $\Delta B = (B_3 - B_1)/2$

$Y_e/f_2 = 1013 - 3.8628\ f_2 \quad (r = 0.93)$

The equilibrium yield (Y_e) and other statistics are listed in Table 13. The annual equilibrium yield in a year is the average annual catch which will cause the fishable stock in a water body neither to increase nor decrease under a given fishing mortality from a given stock. Estimation of the relation of the annual equilibrium yield to the effective fishing effort is expressed as follows:

$$Y_e = 1013\ f_2 - 3.8628\ f_2^2 \quad \ldots\ldots\ldots\ldots\ldots (10)$$

(where Y_e = equilibrium yield and f_2 = effective fishing effort)

Derivation of the above relation is given by Ricker (1975) and illustrated in Chen (1976). The maximum sustainable yield curve based on equation (10) is shown in Fig. 21. Clearly, the fishery has collapsed since 1984, as far as the availability of fish over 45 cm is concerned. Overfishing in four consecutive years, 1980-83, is undoubtedly the main reason behind it. The derived parameters for the catchable stock are as follows:

B_m (maximum stock size) = 179,272 fish;

F_s (rate of fishing at sustainable level) = 0.74;

B_s (stock size at sustainable level) = 89,100 fish; and

Y_s (maximum sustainable yield) = 66,400 fish.

7. CATCH OF OTHER SPECIES IN THE FISHERY

The catch of other species of fish in the commercial fishery has been mostly less than 4% of the catch of whitefish, both in terms of number and weight, with walleye and pike comprising the greatest proportion (Table 14). The catch of these two game fish species increased noticeably in 1983 and 1984. Since there is no tolerance on game species, fishermen are encouraged to return live game fish to the water and give dead ones to the Conservation Officers. The harvest statistics, as shown in Table 14, are lower than what the commercial nets have actually caught. The unusually high numbers of both walleye and pike in 1984 might have been related to bad weather in that season resulting in higher net mortality due to net entanglement.

A small quantity of cisco has begun to appear in the catch since 1982. Because of its non-market value, cisco have normally been discarded and not recorded, except in the 1984 season in which 3,000 kg were marketed through a fish plant from the Freshwater Fish Marketing Corporation.

Fig. 21. **Maximum Sustainable Yield Curve, Lake Diefenbaker Commercial Fishery, 1976-85.**

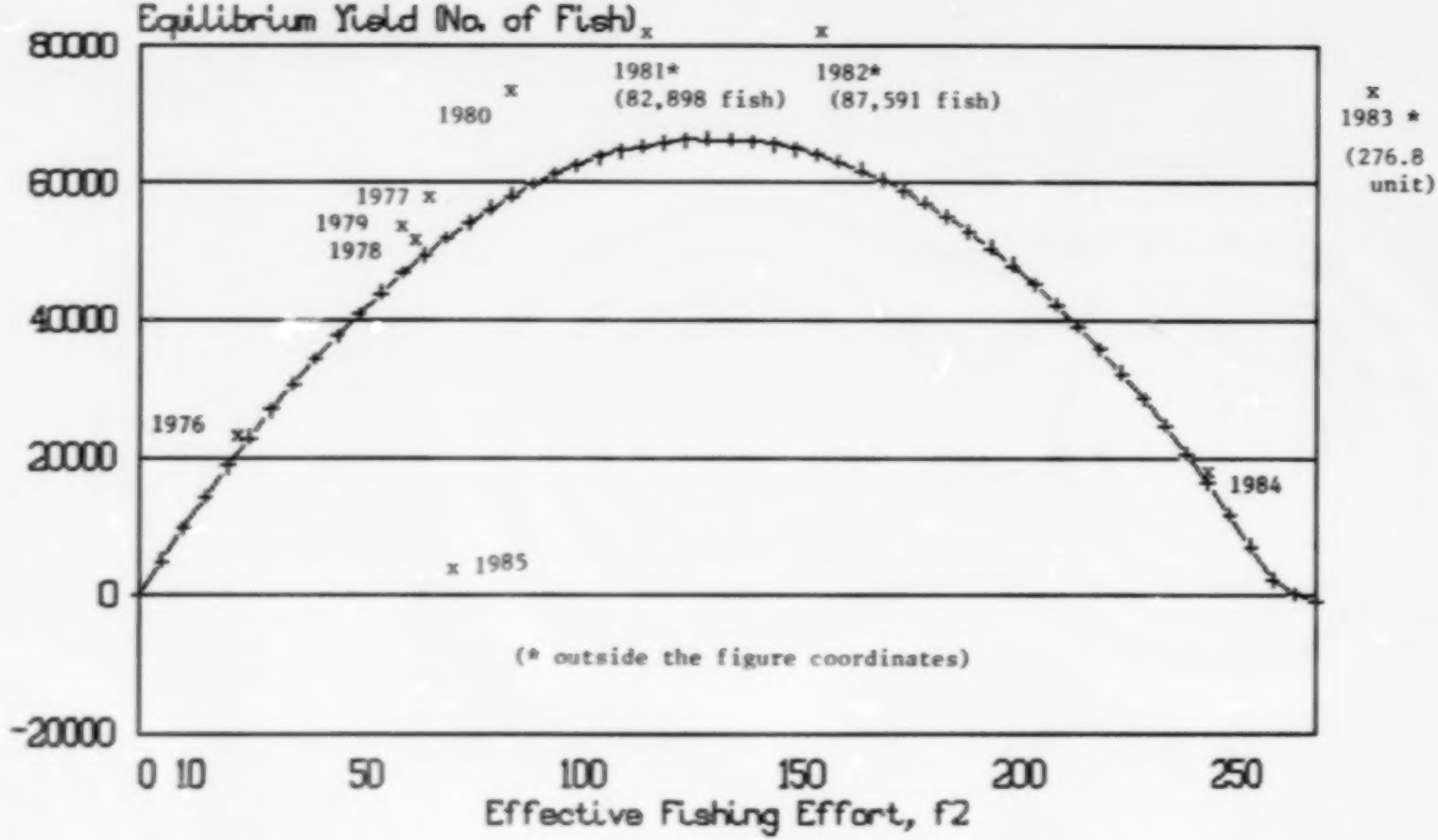

Table 14. Production of other species of fish in the Lake Diefenbaker whitefish fishery, 1976-84.

Year		Walleye	Pike	Goldeye	Sturgeon	Cisco	Trout			Total	% of whitefish catch	
							Rainbow	Lake	(Both)		All species	Gamefish**
1976	No.	(Negligible - on the average, no more than 1 fish/day taken)										
	kg											
1977	No.*	593	180	184	--	--	10	9	(19)	976		
	kg*	937	1044	226	--	--	20	36	(56)	2263	2.5	2.2
1978	No.	315	69	--	--	--	--	8	(8)	392		
	kg	497	400	--	--	--	--	23	(23)	920	1.2	1.2
1979	No.	99	32	50	5	--	?	?	(9)	195		
	kg	157	186	61	10	--	?	?	(26)	440	0.5	0.4
1980	No.	306	69	255	12	--	?	?	(81)	723		
	kg	483	402	314	24	--	?	?	(244)	1467	1.4	1.1
1981	No.	440	74	41	5	--	4	5	(9)	569		
	kg	695	432	50	10	--	8	20	(28)	1215	1.1	1.0
1982	No.	203	140	433	--	--	30	6	(36)	812		
	kg	321	811	532	--	--	93	24	(117)	1781	1.8	1.2
1983	No.	907	248	13	--	--	93	--	(93)	1261		
	kg	1433	1439	16	--	--	183	--	(183)	3071	3.5	3.5
1984	No.	739	265	82	--	6000	?	?	(22)	7108		
	kg	1167	1538	101	--	3000	?	?	(66)	5872	29.7	14.0

* Conversion between the number and weight is based on the following average weight of fish in the catch: walleye - 1.58 kg, pike - 5.8 kg, goldeye - 1.23 kg, sturgeon - 2.0 kg, cisco - 0.5 kg, rainbow trout - 1.95 kg lake trout - 4.0 kg.

** Walleye, pike, rainbow trout and lake trout.

An increasing number of rainbow trout has been caught in the fishery, mostly in the south end. Less than 10 lake trout are caught each year, mostly in the area near Gardiner Dam.

The overall catch of game species by the fishery has been negligible, relative to the populations existing in the lake.

8. FISH COMMUNITY

There have been two major changes with respect to the fish community in Lake Diefenbaker since impoundment. Firstly, there is an enormous increase in the biomass of fish due to the increase in lake productivity, and secondly, the replacement of riverine species by lacustrine species as the dominant fish.

From the initial survey period in 1967-69 to the early 1980's, the number of all species has increased remarkably, especially that of whitefish, walleye, perch and cisco - typical lake inhabiting species (Fig. 22). Goldeye, once the dominant species in the river and during the first few years after impoundment, has become a minor species.

Distribution of the riverine species, such as goldeye, mooneye, and sturgeon, are now by and large restricted to the upstream portion of the lake, between Saskatchewan Landing and Riverhurst. The lacustrine species are widely scattered throughout the entire lake, occurring at different depth zones in the summer months : 3-15 m for walleye and pike, 15-50 m for whitefish, near shore at 1-5 m for perch and offshore at the upper 10 m for cisco.

9. CONCLUSION

The physical alteration of the South Saskatchewan River has resulted in new ecological characteristics of Lake Diefenbaker, namely, loss of riverine hydraulics, greater water capacity, increased biological productivity, adaptation of aquatic life to a stationary, deep cold environment.

The present study has invalidated two previously held notions that 1) the Lake Diefenbaker whitefish are fast-growing fish with a rather short life span of only 5-6 years and 2) that because of annual water draw-down the population has little chance of perpetuating itself through natural reproduction. On this basis, the commercial whitefish fishery was initiated to harvest the catchable stock as quickly as possible with large mesh nets before nature took its toll. It is apparent that the Lake Diefenbaker whitefish are slow-growing and long-lived fish, compared to other populations in Saskatchewan; and that the population has been able to sustain itself through successful natural reproduction in areas beyond the effect of winter water draw-downs. The huge concentrations of spawning fish moving

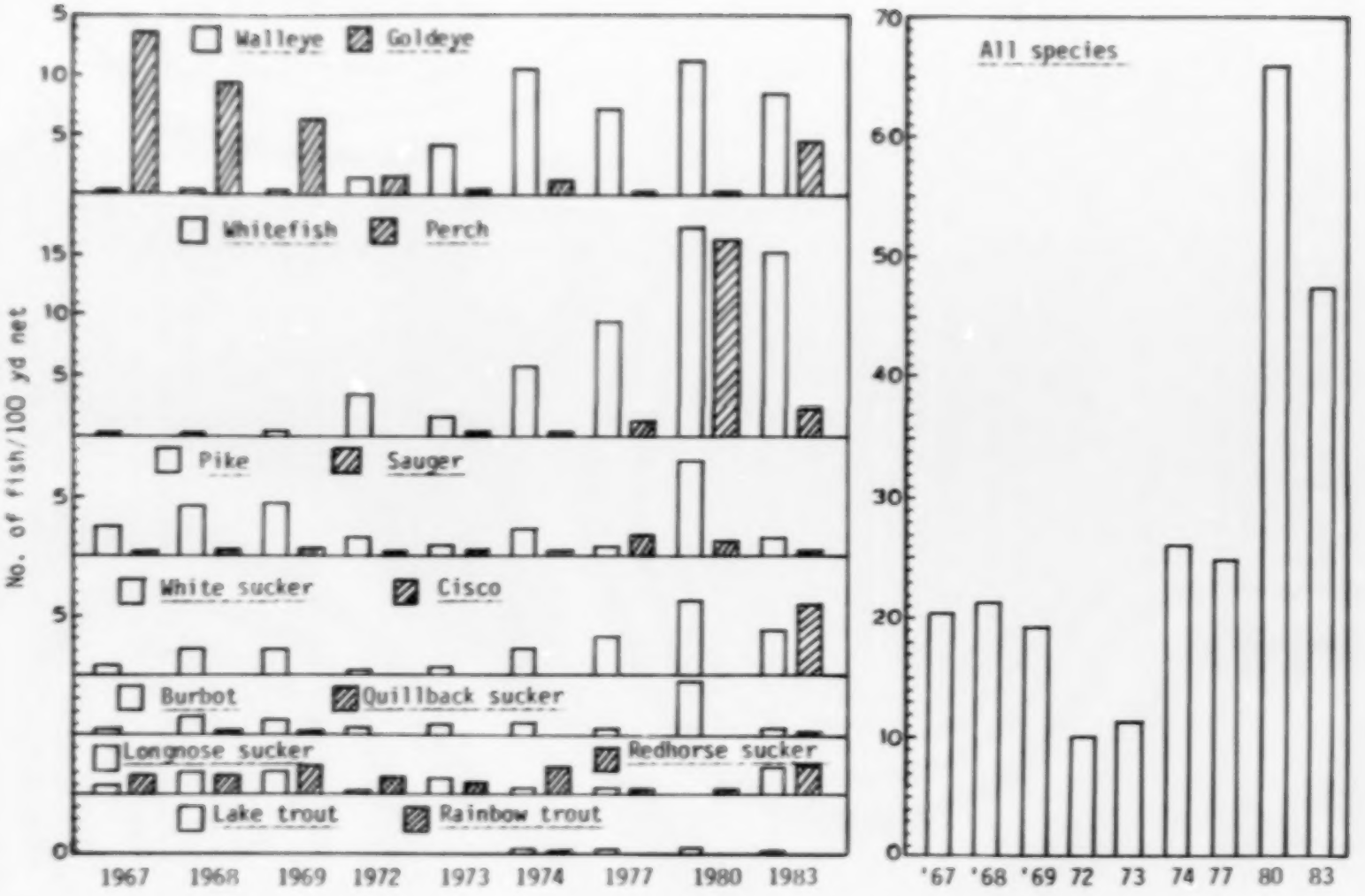

Fig. 22. Catch (no.) per 100 yard of standard gang gill net for major species of fish, Lake Diefenbaker, 1967-83.

toward the Saskatchewan Landing and Coteau Bay areas in the fall seems to suggest the population has retained its indigenous river spawning attribute. The stocked whitefish have also originated from a river spawning population in the Pierce Lake-Cold River system.

In light of reports of increasing number of "razor back" fish in the population, the mixture of indigenous and stocked whitefish in the lake has raised an interesting question as to the racial character or integration of the current population. The differences in growth rate, maturity and reproduction capability of these two races, if any, would have some bearing on the susceptibility to fishing, stock recruitment, condition etc. In this regard, unfortunately, much remains unknown.

In a fisheries appraisal, knowledge of fish ages is essential for describing the biological attributes of a fish population, such as growth, maturity, stock recruitment, natural and fishing mortality rates and other parameters in order to detect significant changes of the population structure in response to fishing and/or ecological modifications. Inaccurate age information derived from the scale method during the early period of the commercial fishery precluded detection of overfishing and depletion of larger fish over 45 cm by 14 cm mesh nets.

The extent to which the whitefish population has continued to proliferate during the period of commercial fishing, as evidenced in the test net results, has more than offset the population loss through natural causes and fishing. In spite of significant depletion of fish over 45 cm in length, the numbers of whitefish larger than 34 cm in length have remained rather abundant; more than 620,000 in 1983 and 530,000 in 1984; as estimated from the mark-recapture study. The low annual fishing mortality rates, 3.24% in 1983 and 11.8% in 1984, indicate a very low level of exploitation toward this group of fish.

Analysis of the virtual population (utilized stock) clearly shows that significant trimming of the large whitefish occurred for four consecutive years beginning in 1980, at a time when the relative proportion of fish larger than 45 cm or older than 10 years began to decrease (Figures 12 and 14) but the absolute numbers of these fish actually increased (Table 9). The effect was also evident in the persistent decrease in the average size of fish caught in the commercial fishery (Table 15). The demise of the commercial fishery under the existing regulations was caused by the use of 14 cm mesh nets and overfishing. The high selectivity of 14 cm mesh nets toward fish over 45 cm had harvested only a moderate portion of fish between 40 and 45 cm and left those under 40 cm in the population practically untouched. The continuous use of this mesh and fast depletion of 45 cm fish had resulted in drastic decrease in the catch per unit of fishing effort (CPUE).

Table 15. Average length and weight of Lake Diefenbaker whitefish in the commercial catches, 1976-85.

Year	Average Length, cm			Average Weight, kg		
	North	South	Lake	North	South	Lake
1976			44.0			1.43
1977			45.1			1.58
1978			45.4			1.46
1979			45.4			1.59
1980	44.6	46.0	45.5	1.35	1.49	1.42
1981	44.8	46.0	45.5	1.23	1.39	1.36
1982	44.1	44.4	44.2	1.14	1.16	1.15
1983	43.8	44.0	43.9	1.17	1.19	1.18
1984	44.0	43.5	43.7	1.16	1.12	1.15
1985		43.7	43.7		1.15	1.15

10. MANAGEMENT OPTIONS

There are two principal management alternatives: do not have a commercial fishery for whitefish on Lake Diefenbaker; or reinstate the commercial fishery. The latter has two options: retain the current legal mesh; or implement a smaller mesh. If it is decided to reinstate a commercial fishery, the objectives of the management plan should be to set an initial total allowable catch (TAC) of 50,000 kg and monitor the fishery annually to ensure harvests are not excessive. This means ensuring the age at full recruitment to the fishery does not become less than 6 years, the survival rate does not become less than 0.5, and that at least 80% of the fish in the fishery are sexually mature.

The first option allows the whitefish population to continue unutilized by man. The lack of fishing pressure will enable it to continue recovering from the overfishing which occurred between 1980 and 1983. Given the fact that the fishery has ceased for six years since 1986 but the portion of the whitefish population larger than 45 cm has not recovered significantly, it is likely that a new ecological balance has existed in the lake, with respect to fish community structure and size compositions within each individual species. Prior to being depleted in around 1983 (Table 3, p 18), the larger whitefish had existed in Lake Diefenbaker in great quantity at a time when other lacustrine fish species were not prevalent. Since then, the newly proliferated populations of ciscoes, perch, walleye, and suckers have undoubtedly occupied the food web niche left behind by the depleted portion of the whitefish population. This means the essential energy that is required for the whitefish population to accumulate once again a large numbers of fish over 45 cm is no longer available. The population will never be the same, as far as the size composition is concerned. Similar cases in point concerning whitefish and other fish populations are numerous in heavily fished lakes in which larger fish have not recovered in numbers once they are depleted.

Lake Diefenbaker does have a population of whitefish which is capable of supporting a small commercial fishery. The fish are of excellent (i.e., "export") quality. The harvestable population is now comprising the "small-medium" fish (i.e., 33-40 cm fish weighing 0.5-0.9 kg), with some in 40-45 cm and only a few larger than 45 cm.

It is not possible to derive a new sustainable yield for a whitefish fishery using the results of the current study. Because the data indicate the MSY for whitefish longer than 45 cm was 66,000 fish, it is likely that an equal, or larger, MSY would be suitable for a fishery targeting smaller fish. If an initial number of 66,000-70,000 fish is adopted as a trial MSY, a TAC of 50,000 kg results.

Reinstating the commercial whitefish fishery means choosing an appropriate mesh. In the previous fishery, 14 cm mesh gill nets selected fish longer than 45 cm, captured moderate numbers between 40 and 45 cm, and left fish less than 40 cm virtually untouched. Because

few whitefish longer than 45 cm remain, implementing the current legal mesh will mean small harvests and unfilled quotas.

Smaller mesh nets will catch smaller fish. Gill nets of 10.2 cm mesh will primarily catch whitefish between 35-42 cm in fork length (Fig. 18) weighing 0.5-1.0 kg (Fig 5). Gill nets of 11.4 cm mesh are about 30-40 % less efficient than the 10.2 cm mesh nets toward harvesting the existing population but will catch slightly larger fish, 39-44 cm (0.7-1.2 kg). The 12.7 cm mesh nets will be selective toward fish larger than 41 cm (Fig 5), which are no longer present in sufficient numbers (Fig. 9) to justify a fishery. Using either 10.2 or 11.4 cm mesh net, the new fishery will mean a potential maximum gross revenue of $55,000 to the fishermen from a harvest of 50,000 kg, based on the May 1992 prices for fish of this size, $1.10/kg.

Smaller fish are also younger, and whitefish 35-44 cm in length are 5-9 years of age (Fig. 4). These fish have only been lightly exploited in the fishery, and using smaller mesh gill nets is to a certain extent equivalent to fishing a virgin population. Fish will be abundant and catch per unit effort high in the initial fishing-up phase, and fishermen may request an increase in the TAC. As the population becomes more heavily exploited, the age at recruitment will fall and more sexually immature fish will be caught. It is imperative to monitor these parameters annually to see if the TAC should be lowered to reduce the rate of exploitation.

Smaller mesh nets will also catch more game fish. If the whitefish are fished in the autumn, catches of walleye and pike should be minimal but as much as 5,000 kg of both species may be caught.

It is recommended that:

1. the whitefish commercial fishery be reinstated in Lake Diefenbaker using 10.2 cm (4-inch) or 11.4 cm (4.5-inch) stretched mesh with an initial total allowable catch (TAC) of 50,000 kg;

2. the fishery be monitored annually to ensure that the age at full recruitment does not fall below 6 years, that the survival rate does not become less than 0.5, and that at least 80% of the fish in the fishery are sexually mature;

3. the game fish tolerance be 2,500 kg for pike and 2,500 kg for walleye; and

4. the fishing season remains in the fall from September 1st to November 15;

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Appendix 1. Regulations and guidelines for the Lake Diefenbaker commercial whitefish fishery, 1976-85.

Regulations:

1. Quota ..... 90,700 kg
2. Game fish tolerance ... Nil
3. Mesh size ..... 14.0 cm (5.5 inch)
4. Season ..... late summer - early fall

Guidelines:

a. Maximum no. of licences 10
(five for north end and five for south end)

b. Minimum size of fishing vessel ... 20 feet

c. Split quota ..... 45,350 kg (north end)
45,350 kg (south end)

d. Boundary for eligible participants.

North end:

Highway 44 to the north
Highway 42 to the south
Highway 45 to the west
Highway 19 to the east

South end:

Grid Road 342 to the north
Grid Road 644 to the south
Highway 4 to the west
Grid Road 644/Highway 45 to the east